PHD

The potential for reduced tillage systems for wheat production under irregated semi-arid conditions: with particular reference to the Sudan and Morocco

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THE POTENTIAL FOR REDUCED TILLAGE SYSTEMS FOR WHEAT PRODUCTION UNDER IRRIGATED SEMI-ARID CONDITIONS: WITH PARTICULAR REFERENCE TO THE SUDAN AND MOROCCO

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MEMORANDUM

The work presented in this thesis is based entirely on the author's independent studies. The author planned and carried out the experimental work and is responsible for all interpretations and conclusions. The assistance of others in recording and statistical analysis is acknowledged.

S.M.I. Elazhari

DEDICATION

To my wife, Nazik, and son, Mohamed Elazhari

. . . and to Life.

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PART TWO - MOROCCO

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ABSTRACT

Tillage has been the subject of discussion at many meetings of agricultural scientists around the world because it is an arduous operation and constitutes a significant part of the cost of producing a crop.

For many years, farmers in the semi-arid areas of North Africa have believed that the more the land was tilled, the better the crop would be. There is now potential evidence to suggest that minimizing tillage operations in these semi-arid conditions (characterized by a long dry period of 6-8 months and one short rainy season which is crucial in crop establishment), where soil moisture is a limiting factor, can have beneficial effects.

Experiments conducted at two locations in the semi-arid regions of the Sudan and Morocco, for one year in each site, compared the similarity and variability of the different treatment/year, treatment/place and treatment/treatment interactions. Of these variables, it became evident, particularly from weather data, that the comparison of treatment/places interaction was the most important.

It was found that reduced tillage (one pass of an ordinary ridger, 5 to 7.5cm deep) just prior to sowing resulted in the highest grain yield at the lowest cost.

The conventional method of tillage, as recommended by the Gezira Agricultural Research Station, Sudan, involving a number of passes of an offset disc harrow, gave a lower work rate at a higher operational cost and a lower yield of grain on the control plots of the experiments.

Direct drilling, which is not used in the Sudan at all and which is a relatively new concept in Morocco, so far used only in an experimental situation, showed potential problems with weeds and also a low grain yield. The cost of the drill and a suitable tractor is also a significant factor against direct drilling in the whole of North Africa.

In the non-traditional areas used for wheat production, particularly in the Sudan, the crop suffers from the short growing season, from heat stress due to the high ambient temperature and poor water management of the 'cracky' clay soil. These problems lead to low yields which are mainly associated with low crop stands: these are mainly associated with poor seed-bed conditions and uneven application of flooding irrigation water.

The potential advantages of the Reduced Tillage System employing the ridger at a shallow cultivation depth, showed improvements in soil physical properties and enhanced germination. This was reflected in increased grain yield. It is cheaper, uses less energy and achieves a higher rate of work. By using implements locally available, it is a simple approach to cultivation requiring few operator skills, therefore it is more likely to be accepted. If it is adopted by resource-poor farmers in the semi-arid regions of Africa, the result is likely to be the increasing or stabilizing of grain yields at optimum cost. Technologies which increase labour or require a significant capital input are likely to be rejected by the farmers.

Several suggestions for further work are made.

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ABBREVIATIONS AND CONVERSION FACTORS

mm	millimetre
cm	centimetre
cm^3	cubic centimetre
m	metre
m^2	square metre
m^3	cubic metre
m^3/h	cubic metre per hour
m/sec	metre per second
km/h	kilometre per hour
km^2	square kilometre
kW	kiloWatt
kWh/ha	kiloWatt hour per hectare
f	feddan
ha	hectare
ha/h	hectare per hour
l/ha	litre per hectare
ha/day	hectare per day
kN	kiloNewton
kN/m	kiloNewton per metre
kN/cm^2	kiloNewton per square centimetre
>	greater than
<	less than
%	percent
g	gram
g/cm^3	gram per cubic centimetre
kg	kilogram
kg/f	kilogram per feddan
kg/ha	kilogram per hectare
kg/h	kilogram per hour

°	degree
°C	degree Celcius
hp	horsepower
rev/min	revolution per minute
kPa	kiloPascal
Mpa	MegaPascal
t	tonne
t/ha	tonne per hectare
m.c.	moisture content
US$	American Dollar
£	Pound Sterling
LS	Sudanese Pound
LS/ha	Sudanese Pound per hectare
Dh	Moroccan Dirham
Dh/ha	Moroccan Dirham per hectare
DP	Disc Plough
DH	Disc Harrow
R	Ridging
RS	Ridge Splitting
SD	Seed Drill
DD	Direct Drilling

Conversion Factors:

1 feddan = 0.420 hectare

1 hectare = 2.38 feddan

1 quintar = 100 kilogram

£1 = US$ 1.54 (1996)

£1 = LS 1488 (1996)

£1 = Dh 14.6 (1996)

1.0 GENERAL INTRODUCTION

1.1 The Importance of Wheat

Wheat (*Triticum aestivum* L.) belongs to the family *Poaceae* (Syn. *Gramineae*); it is the world's most important cereal crop. In recent years, it has become an increasingly important cereal in many developing countries, particularly in Africa. In several African countries, there has been rapid urbanization; the majority of people have changed their preferred food crop to wheat from sorghum and millet (Damous, 1986 and Olugbemi, 1991). However, there are supply problems as African yields are low and the total wheat production is limited (**Table 1.1**).

Wheat is multi-purpose, providing human food, livestock feeds and a wide range of farm and industrial raw materials. Wheat straw is also used as a fuel, fodder and bedding for livestock. Wheat shares with rice the distinction of being separately classified by the United Nations Food and Agriculture Organization (FAO), whilst all the other cereals are termed coarse grains.

1.2 Climatic Range

Wibberley (1989), citing the Bible (Genesis 42: 1-3) and Gompertz (1927), states that it is generally agreed that cereal cultivation started some 6,000 years ago in the fertile crescent of the Middle East, probably around Jericho, Israel and in Egypt.

In the tropical and sub-tropical areas, the most important crops are rice, sorghum, maize and millet. However, in temperate regions, wheat is the most important crop, but it is also found at medium and high altitudes in the tropics. Varieties of wheat are available to suit various altitudes, up to 2,800 metres above sea level.

Table 1.1 Major Food Crops

Crop	Area in Africa (1000ha)	Africa Production (1000 t)	World Area (1000 ha)	World Production (1000 t)	Percentage of African Contribution to World Production (%)	Average of African Yield (kg/ha)	Average of World yield (kg/ha)
Wheat	8,801	16,157	215,921	527,982	3.10	1,836	2,445
Rice	7,235	15,855	146,452	534,701	2.97	2,191	3,651
Maize	21,316	37,825	131,528	569,557	6.64	1,775	4,330
Potatoes	745	7,981	18,191	265,436	3.00	10,713	14,591
Barley	5,472	6,494	73,512	160,810	4.04	1,187	2,188
Sweet Potatoes	1,384	6,944	9,380	124,339	5.59	5,017	13,256
Cassava	9,481	72,779	15,819	152,473	47.70	7,676	9,639
Soya Beans	501	603	62,653	136,725	0.44	1,204	2,182
Sorghum	21,009	15,833	43,718	60,951	25.98	754	1,394
Millet	18,214	10,758	37,710	25,982	41.41	591	689
Oats	947	239	19,749	33,735	0.71	252	1,708
Tomatoes	428	8,315	2,852	77,540	10.72	19,414	27,184
Rye	58	23	11,012	22,588	0.10	401	2,051

Source: Food and Agriculture Organization, Production Year Book, 1994.

Wheat grows well on most well-drained soils; the minimum temperature for growth is some 3° to 4° C, optimum is 25° C, and maximum about 30° to 32° C. Daytime temperatures of about 30°C encourage rapid growth and development, but generally do not result in high grain yields, simply encouraging vegetative growth.

Wheat is mostly grown where annual precipitation averages 25 to 175cm and for optimum yields, an annual rainfall of 25 to 100cm is required. Seasonal rainfall distribution is also important and needs to match the requirements of the developing crop (Ouattar and Ameziane, 1989).

1.3 Agronomic Factors Influencing Wheat Production

Despite continuous scientific and technological progress, several of the environmental factors affecting crop growth are still uncontrollable under field conditions. The weather remains the main factor outside the producer's control and in many areas and with many crops, this is the chief cause of fluctuation in yield. Other factors include the soil, pests, diseases and weeds.

The amount of energy from solar radiation is the ultimate physical factor limiting crop growth rate when all other restrictions are removed. Monteith (1966) has reviewed the physical limits of crop production and concluded that the main reason for the difference between average yields under experimental conditions and in commercial practice could be attributed to preparation of seed-beds: this difference can also be related to deficiencies in available nutrients and water supplies, losses through weed competition, diseases, pests and losses at harvest.

To achieve the best possible yield, it is appropriate to select a crop (or variety of a crop) to suit local environmental conditions, to develop an adequate leaf area index for rapid and sustained crop growth rate and then to maintain an appropriate supply of water and nutrients whilst protecting the crop from pest and disease attack.

Wibberley (1989) has neatly summarized the factors influencing the husbandry of cereals in Britain, including both the positive factors such as soil potential and fertilizers and the negative factors such as weeds, pests and diseases (**Figure 1.1**).

1.4 North African Systems for Growing Irrigated Wheat

The most important gravity-fed irrigated wheat growing areas in North Africa are found in Egypt, the Sudan and Morocco.

In North Africa, the traditional agricultural sector operations in irrigated areas (using gravity-fed surface irrigation) are carried out with simple hand tools of a type that have been used for centuries without being improved significantly. Most of the tools are used for soil loosening and partial inversion of soil and seed-bed preparation. They are well adapted to this sort of work in most of the regions but are generally made of relatively short-lived materials. Using hand tools, a man might require about 30 hours to complete a task which could be undertaken in one hour by one horsepower of machine power (Craig, 1991): a consequence of urbanization is that there is a limit to the amount of labour available that is able-bodied enough to undertake this basic cultivation work, so the scope for increasing wheat production without some form of mechanization is not great.

The progression to animal-drawn implements (usually denoted as intermediate technology) generally provides an opportunity for increasing the production of crops in rural areas (Hopfen, 1981; Crossley and Kilgour, 1983).

In the Sudan, the use of animal-drawn implements first became apparent in the northern regions, but in the western regions, use developed only slowly as there were no local blacksmiths to service the implements.

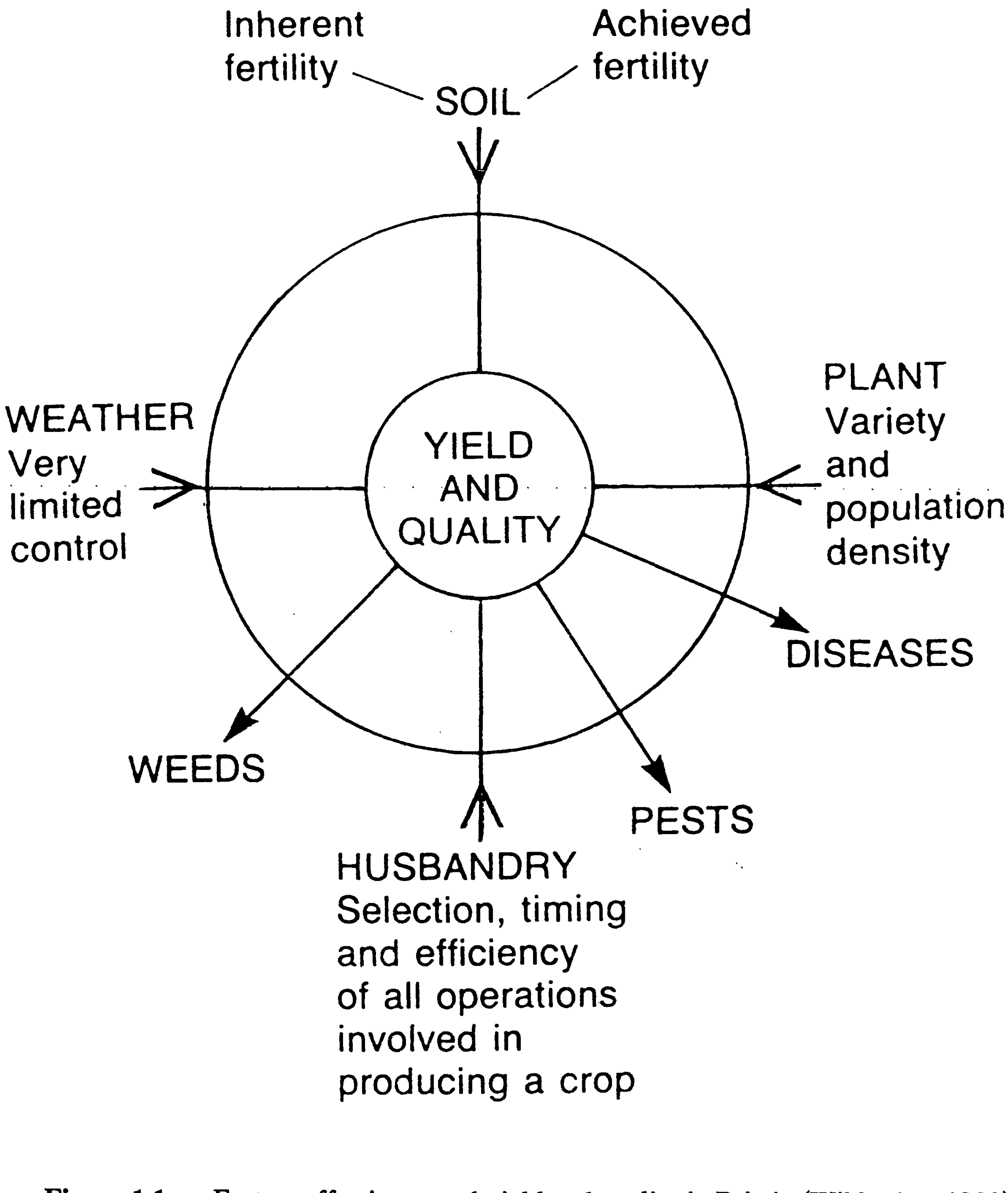


Figure 1.1 Factors affecting cereal yield and quality in Britain (Wibberley, 1989).

Later, field implements for the traditional farmer were manufactured locally. Animal powered cultivation was also utilized in some neighbouring countries in North Africa, particularly in Egypt and Morocco, where oxen-pulled ploughs, cultivators and small simple seeders were used to grow arable crops. These were made in local workshops and exploited any available local materials.

It is now generally accepted by farmers that rapid expansion of the area cultivated and increased density of land use in North Africa will, in most situations, require significant increases in power inputs for such operations as cultivation, weed control, harvesting and transport. The increased power input will possibly be derived from a combination of hand labour, draught animals and engine power.

Smallholder agriculture plays a very important part in most North African countries and this sector is vital in providing food for the majority of the rural population. Those farmers producing excess produce will be able to trade or sell it, either locally or to the urban markets and, in the case of some commodities, even into an export marketing system. In all cases, this constitutes a very important contribution to the economy of the country. Some governments have realized this; for example, in the Sudan, in the mid-1940s, land was distributed to private sector operators with a subsidy to procure medium-range tractors of 50-60hp (Craig, 1991). Later on, an increase in power utilization was considered feasible and, more recently, there is the trend towards much higher horsepower tractors, up to 200hp or more, in certain large-scale investment enterprises.

1.4.1 Wheat Production in the Sudan

Wheat (irrigated and non-irrigated) has traditionally been grown only in the northern area of the Sudan and was grown and used locally (Ageeb *et al*, 1986). In some years, the crop can be grown satisfactorily with minimal irrigation, but in other years, more substantial amounts of water are required.

Wheat was first introduced in the Gezira Scheme in 1942; in this region, practically all the crop water requirements must be met by irrigation. However, production was discontinued after only one year because of poor yields, high production costs and competition with cotton for labour for harvesting. Climatic conditions in the Gezira were considered at the time to be less favourable for wheat production than for cotton, the latter being an exportable, foreign currency-earning commodity.

Approximately twenty years ago, many people in the Sudan changed their preferred food crop to wheat, instead of the traditional sorghum and millet. Demand for wheat grew faster than domestic production, so wheat imports increased substantially. Unfortunately, this caused problems by increasing competition for Sudan's meagre foreign exchange resources.

Early in 1990, the Sudanese government, after facing severe budgetary and trade deficits and reduced food aid, issued a new policy designed to achieve self-sufficiency in wheat production. The new policy banned the importation of wheat into the country and set targets to expand the area sown to wheat to 462,000 ha in 1991 (FAO, 1992). It was decided that this increase should be at the expense of cotton, despite cotton having the role of an important foreign exchange earner. The cotton area has declined in the 1990s by more than half. Much of the expansion of the area of wheat grown has taken place outside the traditional wheat-growing north.

The Gezira wheat area has expanded substantially since 1992, but yields have been disappointing. It has been reported (Hassan and Faki, 1993) that the average yield achieved has only been 1.36 t/ha, only 6% higher than the average of 1.28 t/ha produced twenty years ago. In their opinion, one of the major factors for this poor performance was the difficulty farmers have in establishing the crop satisfactorily.

Babiker *et al* (1991) had meanwhile been studying the major causes of poor establishment of the wheat crop which were affecting yields on the heavy clay vertisols (the main soil type in the Gezira) under irrigated semi-arid conditions. The main factors they identified were:

- Inadequate land preparation, including field levelling.
- Excessive water application at planting time.
- Inadequate seed depth which leads to the seed being washed out by the applied water.
- Failure to germinate due to excess water (flooding during the first watering) and lack of sufficient moisture due to the uneven field levels.
- Damage by termites and birds.

These conclusions by Babiker *et al* (1991) have been reinforced by several other writers (Ageeb *et al*, 1992; Hassan and Faki, 1993) who have also highlighted the fact that seed-bed preparation and crop establishment practices for wheat production in the Gezira need to be improved if optimum yields are to be achieved. However, only limited experimental work has been done on all aspects of wheat cultivation.

Clayton (1983), an agricultural economist, also says that 'increased yields should result from better seed-bed preparations. If used with skill, a tractor will certainly produce a better seed-bed than hand labour, particularly on heavy soils.'

At the same time as the above work was published, the present writer, who is Sudanese, had been involved in research in the U.K. at the University of Nottingham aimed at simplifying the production of seed-beds for cereal production (Elazhari, 1992), and kept abreast of agronomic activities in the Sudan through the Agricultural Research Corporation Annual Reports.

The present writer wished to carry out further research and development work in the U.K. for his PhD study on the techniques used in Western Europe for cultivation, seed-bed preparation and establishment of wheat, with a view to the possible transfer of some of these techniques to the production of wheat under semi-arid conditions in the Sudan. It seemed logical to attempt to contribute to the solution of the problem in his own country, the Sudan, and so a discussion regarding this matter was held with his supervisor. He advised the writer to continue his research work in another British University where work with wheat technology was in progress.

At the same time, the present writer wrote to the National Co-ordinator of Wheat Production Research at Wad Medani asking about the possibility of carrying out experiments on land preparation for wheat production in the Gezira - Sudan, for one year.

The present writer has taken out a loan from King Faisal Foundation endorsed by the Sudanese and Saudi Arabian Authorities, to cover only the cost of his tuition fees whilst at the study, this loan being repayable over a period of years once the writer has returned to his post at the University in the Sudan. Other costs have been paid by the University of Khartoum, to enable this research programme to be followed. Research into wheat production was taking place at the Royal Agricultural College in Cirencester and my Supervisor (at Nottingham) contacted Mr H. Catling, Head of the Farm Mechanization Department at Cirencester, who invited the writer to visit the College to discuss the outlines for his proposed research.

About the same time, the writer received a positive reply from the National Co-ordinator of Wheat Production in the Sudan (Professor Ageeb) agreeing to help with the research in the Gezira. He also provided up-to-date information about the current research programme of wheat production in the central area of the Sudan.

Accordingly, the writer visited the Cirencester wheat technology research team (Mr H. Catling, Dr M.J. Gooding and Professor W.P. Davies). They agreed with the outlined research project and advised the writer to register for a research degree (MPhil/PhD) at Bath University. Dr M.J. Sargent, who agreed to be one of the supervisors, has strong links with the Sudan, and has visited there on several occasions. Bath and Gezira Universities have a history of joint research projects.

After six months at Cirencester undertaking a preliminary review of literature and corresponding with Professor Ageeb and the Head of Agricultural Engineering at the Gezira Research Station in Wad Medani, a detailed research proposal was agreed with Professor Ageeb, the Dean of the Agriculture Faculty at Shambat and the staff at Cirencester. Ten months were then spent in the Gezira where the first set of field experiments was conducted at the Gezira Agricultural Research Station Farm.

It was originally intended that a second year be spent in the Sudan, but Professor Ageeb, Director of the Agricultural Research Corporation at Wad Medani, drew the writer's attention to the fact that similar work was also being undertaken in Morocco. On his return to England to analyse the first set of experimental data, the writer's supervisor at Cirencester contacted the leader of the research team in Morocco, Professor Dr H. Knechtges of Nurtingen Fachhoschule in Germany, who also happened to be a friend of his. After considerable thought and discussion, it became increasingly evident that there were advantages in continuing the research work in Morocco, where the conditions were basically similar to those in the Gezira (soil type, weather conditions, use of flooding irrigation, difficulty in establishing wheat and low yields).

A major advantage of this opportunity was that technical facilities in Morocco were more advanced, including a Massey-Ferguson Autotronic tractor which has many electronic features built in as standard equipment. These features were further enhanced by the addition of a data logger, electronic fuel consumption recorder and a radar control unit to activate the electronic recording systems at the start and stop points of each test. The availability of such equipment enabled recording to be more accurate and for tests to be done with greater speed and ease. In contrast, the technical facilities available in the Gezira were limited and did place restrictions on certain aspects of the research programme.

Also in Morocco, in addition to the availability of a tractor of advanced design, direct drilling was being undertaken as a part of the experimental programme. This presented an opportunity to include direct drilling in the research; this had not been possible in Sudan as the technique is so far not used in the country.

The opportunity was also presented to see and work with different types of equipment to those available in Sudan and to see the research methodology used in a different country. A further opportunity was afforded by the fact that Morocco is a former French colony; French language is commonly used and most of the scientific work is recorded and communicated in French. The two countries have experienced different colonial influences on their agricultural development in this century.

It was also envisaged that the work would complement a project financed by the European Community already set up at two locations in Morocco to conduct field trials on tillage systems with the intention of reducing the production costs of wheat.

Due to the availability of much better facilities, it was eventually agreed that it would be beneficial and preferable to continue the work in Morocco rather than proceed with a second year of experimentation in the Sudan. This was agreed even though the stay in Morocco involved the writer in increased costs, as he was responsible for meeting certain charges involved in his personal research programme. It also provided a good opportunity to assess the treatment/place interactions. Preliminary assessments of geological and meteorological data in the two countries had indicated considerable similarities between the experimental sites.

1.4.2 Wheat Production in Morocco

In Morocco, hand-broadcasting of wheat and barley is common, followed by one pass of an offset disc harrow for seed covering. The main disadvantage of this is that it requires a high input of labour and there is also a need for very high seeding rates (175-350kg/ha) to compensate for the loss of seed placed too deep to emerge or left on the soil surface to be eaten by birds (Moore *et al*, 1993).

Now, the most commonly used implements for wheat production are the disc plough and the disc harrow, especially on the heavy clay vertisols of the semi-arid regions. The quality of work of these implements is frequently poor; it is common to find that three to five passes are necessary to produce a seed-bed and the cost is excessive. The more unfavourable effects of multiple tillage operations are moisture loss, through excessive evaporation, and soil compaction caused by tractor traffic. Poor establishment often follows and subsoiling is usually required every two to three years (Ryan *et al*, 1992). Commenting on this situation, Dycder and Bourarach (1992) concluded that '... for these reasons there is a need for establishing new types of tillage systems which correspond to the pretensions of cultivation in semi-arid regions in quality of work as well as in efficiency.'

The results obtained by Bansal *et al* (1994) from work carried out in the semi-arid regions of Morocco during the season 1990-91 (before the drought years began) showed that sowing wheat using a conventional seed drill at a seed rate of 120kg/ha produced an average increase of 7% (152kg/ha) in grain yield compared with the farmers' practice of broadcasting at 180kg/ha.

Recent work (Bahri and Bansal, 1992) in Morocco on wheat establishment has included an investigation of the suitability of direct drilling. The potential advantages of direct drilling include a lower labour requirement, lower moisture loss and a low cost operation when compared with conventional cultivation. The retention of organic matter on the surface of the soil where it can help to stabilize the soil is also a potential benefit of direct drilling. Direct drilling does, however, have drawbacks, namely the cost of the equipment and problems associated with weeds.

A major factor in producing wheat is the establishment of an adequate plant population early in the crop life: if the seedlings are not present in satisfactory numbers early on, then subsequent tillering appears to be unable to compensate for their absence.

The constraints imposed by the reliance on flood irrigation for the supply of water have also to be recognized, as has the non-availability of instruments for measuring water flow.

Realistically, any improvement in crop establishment techniques in the immediate future probably has to rely on better use of facilities that are already present and fairly widely available, namely 50-60 hp wheeled tractors and relatively simple cultivation equipment.

Since disc ploughs and disc harrows have given disappointing results, it is necessary to examine the possibility of using other implements. The one that was thought to offer some potential was the ridger, an implement that is made locally, which is simple, rugged and easy to operate. It is used extensively in the growing of vegetable crops and in conjunction with irrigation water distribution. It can be operated relatively cheaply and quickly on a range of soil types and at varying depths. Tined equipment was also considered, but on balance it was decided that the ridger had the better potential so a method of using it to produce a wheat seed-bed was devised. It was considered that it should be possible to use it twice at a relatively shallow depth with an interval of 4-6 weeks between the two operations and that at some stage after the second pass, drilling/broadcasting/levelling should be carried out.

This may appear to be an extremely simple process, but it was discussed with several people who have experience in cultivation work: no major drawbacks were predicted and as far as could be ascertained, it appeared to be a 'new' approach.

It was thought that the use of a ridger might encourage more even distribution of irrigation water, even on land that had not been precisely levelled and that the two operations, combined with a levelling operation and/or drilling would produce a sufficiently fine seed-bed for satisfactory emergence.

1.5 The Hypothesis

A hypothesis has been adopted to give future direction and coherence to the thesis and to be a logical basis for justifying and assessing the research programme. The specific hypothesis adopted follows logically from the foregoing literature review and is:

> There is potential for improving the yield of wheat in North Africa through a modification of the cultivation systems used.

1.6 The Layout of the Thesis

Hereinafter the thesis is set out as follows.

In the remainder of this chapter: first, the role of farm mechanization in wheat production generally is reviewed; aspects of cultivation of the crop are outlined and soil management and seed-bed preparation as they are applied on various soil types are discussed. Also considered are the various types of implement and machinery used and their effects on soil compaction.

Campbell (1990) stated that in most developing countries, agriculture is still the main activity of the majority of the people. Recently, however, the transfer of technology from developed to less developed countries has caused quite rapid change. This is also a major component of the research reported here and thus the potential for the transfer of cultivation techniques for wheat production to North Africa from the more highly developed western world, in particular from the United Kingdom is highlighted.

A specific review, in some detail, of the various techniques of cultivation used in the United Kingdom, including ploughing, minimal cultivation, direct drilling and other considerations of using presses, power harrows and various types of rolling cultivation to achieve suitable seed-beds then follows.

The remainder of the thesis is divided into three parts. Part one relates specifically to the Sudan and includes a literature review and details of the experimental work conducted there. Part two relates to Morocco: this also includes a literature review and details of the experimental work carried out in that country. Part three is a general overview discussion of all the scientific aspects of the experiments and the wider implications of the results to farmers and agricultural scientists in North Africa are evaluated. Suggestions for further work are also made.

1.7 The Role of Farm Mechanization

1.7.1 Introduction

Since World War II, techniques of crop production in Europe have been revolutionized by developments in, and uses of, mechanical power. Profitable crop production has depended increasingly on the effective use of land and power, which has been facilitated by the application of new mechanical methods. Mechanical power has steadily replaced the slower and relatively more expensive horsepower and manpower. Developments in mechanization of crop production have resulted in greatly increased output per man-hour, which in turn has helped to offset the effects of rising wages and a reduced labour force. However, it has become more and more evident, in the vital interest of containing production costs, that expensive machinery must be maintained and used with skill.

Mechanization has affected crop production in two main ways. Firstly, by providing extra power, mechanization has enabled heavier and more difficult tillage operations to be undertaken, such as deep ploughing and subsoiling. It has also made possible large-scale reclamation work, and soil levelling to improve and extend mechanized crop production.

Secondly, mechanization has speeded up work. The tractor need neither "tire nor perspire". The extra power, speed and persistence of the tractor enables rapid ploughing, drilling, harvesting and handling operations. In this way, mechanization can be used to exploit favourable weather conditions to the full.

1.7.2 Soil Management and Seed-bed Preparation

Soil management is generally directed towards profitable crop production and the maintenance or improvement of the inherent capabilities of the soil. The aim of soil management is to provide a suitable medium for germination and crop growth and to give protection from harmful effects of weeds, diseases and pests. It also includes such factors as drainage and the incorporation of crop residues and manures into the soil.

A satisfactory tilth will not only provide a suitable environment for seed germination and root growth, but will also benefit soil erosion control and moisture control and will provide optimum air availability for plant growth without creating large voids among clods or soil particles.

The seed-bed should be as free as possible from weeds, and any applied fertilizer should be incorporated evenly in the soil. There are generally three stages in the process of seed-bed preparation, and these may involve the use of several different cultivation implements. The first stage usually consists of loosening the soil by ploughing or by some relatively deep tined cultivation. The second stage involves creating a tilth and the third stage or levelling and perhaps consolidating the tilth.

The type of soil and its previous use will dictate the need for and severity of each process: on some soils one or more of these stages may be omitted - for example, it may be possible to drill directly after ploughing. In other cases, equipment designed to achieve several operations in one pass may be used. In come circumstances, as will be discussed later, a 'no-till' or direct drilling approach may be used. However, assuming that there are three stages, they may proceed concurrently or at intervals following spells of weathering of the soil by exposure to changing conditions.

In seed-bed preparation, timeliness of cultivation is supremely important, especially on heavy clay soils, which may change quickly from being too wet and sticky to work to being too dry and 'cloddy' for ideal working. Opportunities to cultivate heavy soils are often limited, but on all soil types the temptation to start cultivation too soon should be resisted, since the passage of heavy tractors and implements when the soil is unfit can cause severe soil compaction and loss of structure with consequent loss in yield (Wall *et al*, 1991).

1.7.3 Soil Compaction

A major feature of the development of agriculture over the last fifty years has been the enormous increase in the level of mechanization. The size of tractors and other machines has constantly increased in both power and weight; bigger implements require bigger tractors and when combined, they have led to increases in the effects of compaction.

Since wheeled tractors became commonplace on farms, they have tended to become ever larger and more powerful. To maximize the efficient use of this power, it is often necessary to ballast them and this has resulted in widespread concern about soil compaction, especially during seed-bed preparation. The compaction effects extend far beyond the working depth of the equipment employed to produce the seed-bed and they may have a deleterious result on crop growth. Attempts to rectify compaction effects can be made between crops by the use of subsoilers and other deep cultivation equipment, but it would be far better to avoid them in the first place, if possible. At present there are two main strategies for overcoming the problem:

- Accept compaction will take place and aim to minimize the area in which it occurs by using the 'bed' or 'controlled traffic approach'. The use of gantry tractors is an extension of this approach.
- To use the low ground pressure approach, i.e. wide wheels and tyres with low inflation pressures together with reductions in machine weight.

1.8 Technology Transfer

The majority of agricultural producers in the developing countries of Africa are small-scale farmers and this is central to any consideration of the introduction of mechanization. By contrast, the modern wheat production systems developed in, notably, Western Europe, North America and Australia, rely for their success on mechanized processes, with minimal input of labour (and no animal input), together with varieties bred specifically for mechanical harvesting. The availability of fertilizers and crop protection chemicals, together with the means of applying these materials, is an integral part of the systems. These systems have all developed for use on farms that are many times larger than those of the world's peasant farmers. Cereal farming, in particular, has tended to become very large-scale; it is not uncommon to find tractors of 100+ horsepower, drills up to 6 or 8m wide are used, sprayers used may be up to 24m wide and combines with claimed outputs of 20t/h and more are available. Having said this, the equipment does not have to be this big, or to have such enormous capacity; it is simply that 'agribusiness' has encouraged the emergence of some very large-scale operations.

However, farmers operating on a more moderate scale can still use smaller versions of the more sophisticated machines and have access to varieties, fertilizers and chemicals used by those who farm on a larger scale. Similarly, there are no fundamental reasons why some of the techniques used in highly developed farming systems should not be passed on to those farming in less well developed economies. This basically is the process of technology transfer that provides those living and working in the so-called developing countries with a chance to benefit from appropriate developments in more advanced economies.

In recent years, the term 'Technology Transfer' has been used widely; however, there is no universally accepted definition. Twiss (1990) even goes out of his way to attribute the phenomenon wholly to the developing world.

For the purpose of this thesis, technology transfer is defined as the transferral of modified, highly developed mechanical power systems of cultivation into the existing lesser developed traditional farming systems in North Africa. The medium for this is the present writer, who aims to utilize some aspects of what has been developed in the U.K. and other developed countries, to improve the cultivation of seed-beds for wheat production in the Sudan. He aims to utilize this technology to ultimately modify cultivation techniques used in the Sudan. This could be of particular importance, since the concept of intermediate technology using animal draught equipment, has largely failed to attract interest among tenant farmers, due to the continued need for the still considerable inputs of labour and the slow rates of work achieved.

Clayton (1976) suggests four possible sources of gain arising from mechanical cultivation: increased yields; increased cropping intensities; a higher value combination of crops and expansion of the cropped area.

The mechanization technology inputs must necessarily be co-ordinated with all other technological inputs such as improved varieties and fertilizers for best results (Esmay and Hall, 1973; Roy, 1990).

The introduction of mechanization should facilitate the optimum utilization of economic resources; the implicit assumption is that farmers will adopt specific equipment if it is available or can easily be made locally. Refusal to adopt a new system might indicate that either the farmer is not in a position to take an economic decision, or that he is not convinced that the adoption of the equipment will be profitable to him.

Technology transfer also has implications generally associated with the employment of labour; these can be critical, particularly that of the displacement of people in rural areas. It has been found in some countries that changes in either methods or economic circumstances have led to rural depopulation, unemployment and increasing migration of rural people to the urban areas which are not capable of absorbing them. Biggs (1978), in seeking to understand some of the processes behind changes in agriculture and rural technology, starts by looking at five different levels of rural technology decision-making and how these levels are interrelated. Case studies from Bangladesh are used to examine social structures and reward systems at different levels of decision-making. Without this examination and necessary change, already existing technologies may still not be used and any new technologies suitable for benefiting the poor may well remain idle. The challenge for development planners is whether they can effect social structures and reward systems so that existing and new technologies are used to address the problems being faced by the rural poor. Simpson (1974) also emphasizes the need for different approaches in the selection of appropriate technologies for agriculture in countries regarded as agricultural (80% currently employed in agriculture) and those regarded as transitional (50% currently employed in agriculture).

There are a number of means by which the productivity of the agricultural population can be raised; the adoption of mechanization is only one of these. Much depends on the population and on the proportion of their time actually spent in agricultural activity.

There is ample evidence that many farmers in traditionally based systems of agriculture work only a few hours each day on their farms; this is particularly true in tropical Africa. Higher agricultural prices would raise returns per hour worked and increase the attractiveness of farm work as against leisure or alternative activities. However, some farmers seem to prefer to use at least a part of the increased income to employ paid labourers, rather than increase their own involvement in farm work.

Education seems likely to decrease participation rates, not only by the removal of child labour, but also through the reluctance of those who have spent several years in education to be involved in the more monotonous types of agricultural work.

In the Sudan, which has only a limited engineering manufacturing capacity, there is a recognized need to import large numbers of general purpose, medium size (50-60hp), four wheel drive tractors which are popular with small farmers in irrigated areas.

With the exception of a few formalities regarding foreign currency, there are no legal restrictions on the importation of machinery, workshop equipment and limited raw materials, such as steel, for agricultural purposes in order to encourage the local manufacturing of basic equipment.

To be successful, however, technology transfer involves the provision of training of operators and also mechanics, to provide reliable maintenance and repair of tractors and machinery. Training in safe operation of machines and in workshops is also of great importance as machinery becomes complex.

Obviously, this whole process cannot be put in place overnight. In some industries, it is possible to import manufacturing facilities, perhaps raw materials and key operating personnel and to produce results in a relatively short time. In agriculture, comprising as it does, many thousands of small individual units spread over the length and breadth of a country, the efforts of any move to improve, modernize and apply the elements of technology transfer, must inevitably be a relatively slow process, taking years rather than months.

The research programme reported in this thesis has been carried out in three countries (the Sudan, Morocco and the U.K.) and has involved four institutions, particularly the Royal Agricultural College, where there is much skill and experience in advanced techniques of wheat production, including cultivations for seed-beds developed over many years. The University of Bath, School of Biology and Biochemistry, has a shorter experience, but a very good reputation in crop physiology and production matters. In the next section, therefore, attention is focused specifically on the state of wheat production technology in the U.K. as an example of modern 'high tech' production.

1.9 Wheat Production Technology in the U.K.

Whilst wheat is a relatively new crop in the Sudan and Morocco, it has been grown for centuries in the U.K. It is for U.K. farmers the most important of the cereal crops and usually the most profitable. This position has resulted from application of the latest scientific principles in all the field operations, as well as the appropriate use of inputs involved in the crop management.

- An impressive indication of technological advance in U.K. wheat production since 1945 is summarized in **Figure 1.2.**

- U.K. farming systems have developed over many years and incorporate rotation systems developed from the old 'Norfolk Four Course' rotation, through mixed farming systems, usually involving cattle and/or sheep as well as the growing of crops; multiple-cropping systems and in some cases mono-cropping systems where cereals are grown continuously. Soil conditions and climate are the overriding factors upon which the choice of farming system depends.

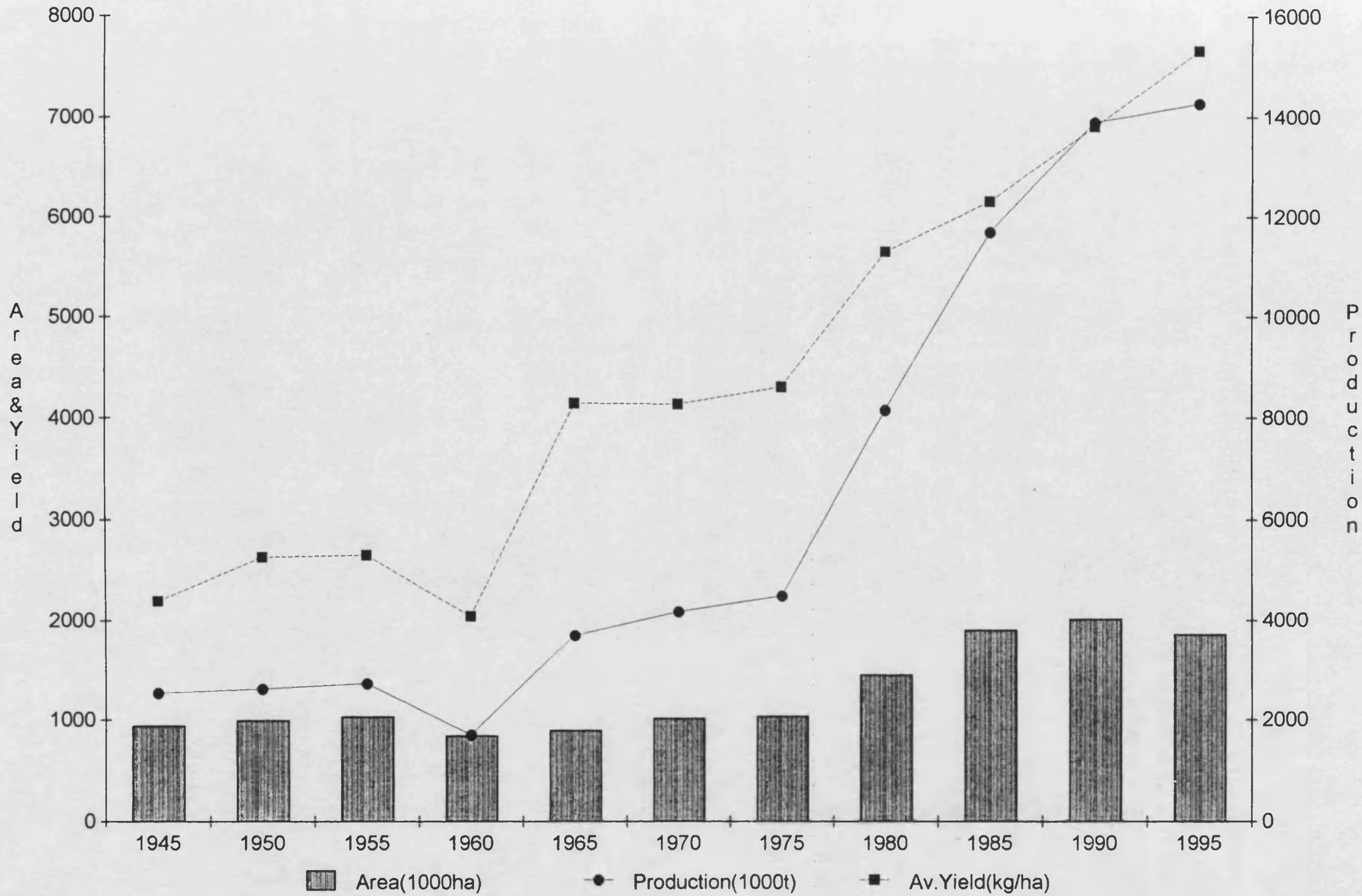


Figure 1.2 Average yield, harvested area and total wheat production, U.K., 1945 - 1995 (Food and Agriculture Organization, Production Year Book).

- This eminent position has not been achieved without effort. Breeders, both public and private, have worked continuously to produce improved varieties, concentrating not only on yield, but also on pest and disease resistance, grain quality and standing ability. Performance of new varieties relative to standard varieties is rigorously assessed by the National Institute of Agricultural Botany.

- The Ministry of Agriculture has played a leading role in improving cultivation techniques through its experiments on various soil types and different climatic conditions at its range of Experimental Husbandry farms. Both university researchers and machinery developers/manufacturers have contributed to the development and assessment of new techniques for wheat establishment.

- A range of techniques has been developed to avoid the use of the plough as a part of the cultivation process, such as direct drilling and minimal cultivation approaches, but many growers have returned to ploughing again after the banning of straw burning.

- The contribution of agrochemical and fertilizer manufacturers to the present high standards of production needs also to be recognized and many prominent farmers have also contributed to development in the use of these products.

- Agrochemical and plant nutrition workers and farmers have built up an understanding of the wheat crop, its behaviour and reaction to various environmental, cultural and physical treatments that would collectively be difficult to match in any other country.

- Agricultural extension, education and training have played an important role to provide farmers and growers with newest scientific techniques and approaches to crop production.

- It is from this accumulated scientific knowledge and the background of sustained effort by all sectors involved, that today's position has been reached: for this reason it is argued that the U.K. is a very suitable technology base from which to launch an effort to improve wheat cultivation in countries which do not have such an extended experience of growing the crop and where research and development resources are limited.

Cultivation techniques and mechanization are the main thrust of this thesis and therefore their role in U.K. wheat production is considered here in more detail.

1.9.1 Cultivation Techniques

Cultivation techniques are performed to prepare seed-beds. Ideally these eliminate weeds, bury trash and provide an environment which is suitable for germination of the seed and subsequent rapid development of the crop.

The application of mechanical power to cultivation, at first generated by steam engines and then by the almost universal use of internal combustion engines, has meant that many different approaches to the process of soil cultivation have been possible.

1.9.2 The Role of the Plough

The mouldboard plough has been the basic farm tillage implement in the U.K. for centuries; when used properly, it inverts the soil, burying surface residues and growth to leave a clear surface which subsequent cultivations and/or weathering will convert into a seed-bed. Since the original horse or oxen drawn single furrow plough, the basic mouldboard shape has remained substantially the same, but has been refined by changes in construction materials and design.

1.9.3 Direct Drilling

In the late 1960s, as relatively cheap and effective herbicides such as paraquat became available, chemical manufacturers and some farmers saw the widespread adoption of direct drilling techniques as an important development in continuous cereal growing. Direct drilling has the advantage of speed and of reducing soil moisture losses, critical points to good establishment of crops in the early autumn, particularly in dry seasons. The cost of establishing a crop by direct drilling is approximately 20% of normal cultivation costs. Direct drills are heavier; this extra weight requires a heavier, higher horsepower tractor to pull the drill. Direct drills are also expensive compared with conventional grain drills.

1.9.4 Minimal Cultivation

At the same time as some growers were becoming involved with direct drilling, others were turning their attention to minimal cultivation techniques - surface cultivations, reinforced whenever necessary by subsoiling and herbicides. This approach was more widely adopted than direct drilling, but it was developed in the days before straw and stubble burning were banned.

Minimal cultivation was used by farmers to save time, enabling large areas of winter cereals to be established quickly. Reduction in tillage also allows savings in machinery costs, labour and fuel inputs (Ball, 1990).

Based on a survey taken in 1985/86, the use of the three main cultivation systems in Britain is shown in **Table 1.2.**

Table 1.2 Tillage systems used in Britain (% of cereal area).

Tillage System	England and Wales	Scotland
Conventional ploughed	85.0	98.8
Reduced tillage	12.0	1.0
Direct drilled	3.0	0.2

Source: Ball (1990)

Of the cultivation techniques reviewed, minimal cultivation would appear to have the most benefits as a possible technology transfer to North Africa and a modified version of the technique employing a ridger operated at a shallow depth (5-7.5cm) was decided upon as the basis of the Reduced Tillage System which is applied in this thesis.

1.9.5 Secondary Cultivations

In the mid-1980s, the use of soil packers and furrow presses increased markedly. Presses have been available for many years and have been 'rediscovered' by growers trying to reduce the number of passes of secondary equipment. According to Kouwenhoven (1989), a press is supposed to reconsolidate the central and lower part of the tillage layer; it should also reduce the depth of ruts by subsequent field traffic and decrease rolling resistance. Packers vary in ring weight, diameter and configuration of the rim, with the optimum type for any situation depending on the soil type.

If further cultivations are needed after ploughing, there are five main categories into which machinery can be classified:

- Tines
- Discs
- Power Harrows
- Ground driven rotors
- Combinations of two or more of the above.

1.9.5.1 Tines

Tined cultivators are designed to rip the soil surface, break clods by loading and moving them around and to mix crop residues with the soil. There are many designs of tine, each manufacturer tending to develop his own design.

1.9.5.2 Disc Harrows

The range of discs available on the market is extensive, varying between wide light sets for surface work, to narrow heavy sets, some with scalloped edges for straw incorporation. The major advantage of disc harrows is their ease of use and their low operating costs. The weight of the individual discs affects the penetration into the soil profile, as does their angle of attack, weights of up to 400kg per disc are available for use in straw incorporation, with lighter discs weighing 75 to 100kg per disc for secondary cultivation work (Howard, 1989). When used for many years on the same land to the same depth, or used in wet conditions, discs may form a pan which can adversely affect crop growth and require subsoiling to rectify the problem.

1.9.5.3 Power Harrows

The use of power harrows has increased considerably in the past decade. Vertical tines or knives rotate at speed, smashing or cutting clods to produce a tilth. These machines can be used as a single pass operation, turning stubble into a seed-bed in very easily worked soils, but more usually, they follow some form of primary cultivation. They are exceptionally useful, but only when operated in the correct way. They should be used primarily to obtain a level, firm, fine tilth prior to drilling in a way that allows a high work rate; when used inefficiently, the fuel and labour costs per hectare increase rapidly, resulting in a costly operation.

1.9.5.4 Ground Drive Rotors

The concept behind these machines is that a rotor, consisting of a series of spikes attached to a horizontal shaft, is pulled along the field at a relatively high speed and the torque produced on this shaft is then used to drive a second rotor which again may be spiked or consist of a series of bars in the form of a cage. The two rotors are coupled by a chain drive, the front rotor turns at a peripheral speed similar to the forward speed whilst the rear rotates 2.5 to 3 times faster. Both rotors are partly immersed in the soil and the effect is to produce a fine surface tilth. The Bomford Dyna-Drive and the SKH Crumbler are the better known implements of this type. Both can be used for straw incorporation or seed-bed preparation. Work rates are high and operation should take place at between 6 and 12km/h (Watts and Patterson, 1984).

1.9.5.5 Combination Implements

Machines incorporating discs with tines or tines and power harrows or presses are increasing in popularity because they lift, break and press clods in alternate banks leaving the soil in a firm level condition.

One design that is fairly popular has a crumbler roller, followed by a bank of 'S' tines, follower by a packer-roller and a spring loaded finger harrow. Each section of the machine can be altered individually for depth and the rollers can be either solid or hollow, depending on the soil type. Another popular combination has a row of scalloped discs followed by a bank of 'P' tines and finally a packer roller or press. This system can be used to a depth of 10cm if required.

The development of pneumatic seed drills has encouraged the uptake of combination equipment which reduces the number of passes made in producing a seed-bed and drilling, decreasing compaction and reducing labour and fuel costs. There are many manufacturers in this sector who offer a power harrow with either a pneumatic or conventional seed drill attached to it in various ways.

With the renewed interest in front linkages for tractors and the need to increase productivity, growers are attaching implements to the front of their tractors. Initially these linkages were used exclusively for front mounted ploughs, but now presses, power harrows and cultivators can all be mounted 'up front' (Marshall, 1991).

The introduction of mechanical power sources has allowed engineers to devise various methods of applying forces to the soil, other than through draught implements. In particular, the idea of combining some form of powered cultivation with ploughing has been followed for at least seventy years (Anthony, 1991).

Elazhari (1992) has taken this one stage further by taking power from a ploughing tractor's hydraulic system and applying it directly to the soil as it is being deposited by the mouldboard. The work done on this soil is such that it breaks up and is thrown sideways in a way that may allow it to be used to cover up seed introduced as an integral part of the operation.

1.9.5.6 Other Considerations

There are greater problems associated with heavy soils, particularly when the time available is restricted, as when winter wheat or winter oilseed rape follows a late harvested crop. In such situations, farmers have the option of either surface cultivation (with problems possibly including soil compaction, trash, volunteers and other weeds, slugs and germination in the decomposing trash) or ploughing. They need to produce soil conditions into which it is possible to drill a crop that will emerge and grow: this can be difficult if the weather is either very dry or very wet.

In recent years, dry autumns have been common and many of those who have chosen to plough medium and heavy soils have also chosen to use either some kind of press attached to the plough or have quickly followed ploughing with an operation such as discing to prevent the furrows drying out too quickly. In wet years, they may well choose to follow the same paths, but those with power harrows, either with or without drills attached, may leave out the post-ploughing and pressing operation.

In situations where time is limited, seed-beds on heavy soils can usually be produced simply by the application of a lot of energy. A wide range of equipment is available and currently the most commonly used include presses, power harrows and rolling cultivators. The amount of energy required may be considerable and several operations might be involved.

Only the presses at present avoid the need to run a separate tractor over the ploughed ground, an operation that obviously runs the risk of over-consolidating the ground beneath the wheels or tracks. Presses have the disadvantage that to be effective, they have to be relatively heavy and so the force required to pull them can be considerable.

1.9.6 Some Techniques of Seed-bed Preparation

Traditionally, seed-beds have been prepared with primary tillage, often involving inversion followed by secondary cultivation to provide an even and fine tilth. There have been many investigations of soil cultivation techniques of which the following are selected examples.

Comprehensive experiments performed in the U.K. by ADAS Eastern Region between 1972 and 1982 set out to evaluate secondary cultivation implements and ploughing. This study confirmed that if an earlier start could be made on ploughing clay soils in dry autumns, more fields could be drilled in optimum conditions in the time available and this could lead to a higher proportion of well-established winter cereals. Secondary cultivation techniques have also been investigated by Cope and Patterson (1989 and 1990) on four different sites with soil ranging from loam to clay, the work involved measuring both energy requirements and the levels of aggregate reduction achieved.

Both draught and power-take-off equipment was used and it was found that on light and loam soils all the equipment could produce a suitable seed-bed in one pass, with few differences between them. On clay soils, however, two passes of draught equipment gave a slightly inferior tilth to one pass with powered equipment. They also found that the disc harrow was the least effective of the draught implements used, it being unable to achieve satisfactory penetration on dried out heavy clay soils. The most efficient soil fragmentation occurred with the Dutch harrow and the Dyna-Drive ground driven rotor type equipment.

Cannell and Ellis (1979) completed long-term experiments on two clay soils to study the effects of different cultivation methods (ploughing, shallow cultivation and direct drilling) on yield of winter wheat using low and high levels of nitrogen fertilizer **(Table 1.3)**.

Table 1.3 Effect of method of cultivation on yield (tonnes/ha) of winter wheat on clay soils in two contrasting seasons. (Levels of significance not reported by authors.)

			Lawford series (35% clay)			Denchworth series (50% clay)	
			Direct-drilled	Shallow-tined	Ploughed	Direct-drilled	Ploughed
1976			5.5	5.2	4.8	6.4	5.8
1978	Low	N	8.6	8.3	9.3	7.5	9.0
	High	N	10.5	10.2	10.2	9.4	10.0

Source: Cannell and Ellis, 1979

They also studied the effects of ploughing and direct drilling on root growth and found that from the beginning of stem elongation of winter wheat (in April) the number of roots at depth (80-100cm) can be increased after direct drilling, especially in dry conditions. On the other hand, in wet seasons on the heaviest soils, direct drilling was found to discourage deep rooting.

Patterson *et al* (1980) studied the economics of tillage systems in a long-term experiment. Reduced cultivation and direct drilling were studied on three sites, Boxworth, Rothamsted and Silsoe, between 1971 and 1977 using plant establishment and crop yield to gauge the suitability of the cultivation technique compared with traditional cultivations. They found that primary cultivation implements such as chisel ploughs and flexible tine cultivators could achieve high work rates even with two passes. Disc harrows were found to perform poorly on wet soils. The best degree of inversion was achieved with the conventional mouldboard plough and the rotary digger (a machine now out of production) was effective on the heavier soils.

However, with secondary cultivation implements, the disc harrow and spring tine cultivator were particularly suited to lighter soils or preparing a seed-bed on heavier soils where a degree of weathering had occurred. The power harrow and spike rotary cultivator can be suitable for producing a tilth for winter cereals from a cloddy soils surface and in weedy conditions. Patterson *et al* (1980) also found that seed-bed preparation with a combination implement allowing a one pass system, may be suited to winter cereals where the previous crop has been harvested late in the autumn, such as potatoes, sugar beet or Brussels sprouts.

Starting in 1972, ADAS, Cambridge (1980) carried out a long-term project at fifteen sites, comparing methods of establishment for cereals, comparing traditional cultivation (ploughed or deep cultivated), reduced cultivation and direct drilling. Grain yield results are summarized by the number of sites where each treatment has given the best yield **(Table 1.4)**.

Table 1.4 Number of sites where each treatment has given the best yield (mean yield is t/ha is in brackets - levels of significance not reported by authors).

	Ploughed or Deep Cultivation	Minimum Cultivation	Direct Drilled
Winter Wheat 1973-1976	9 (5.4)	10 (5.3)	13 (5.4)
Winter Wheat 1977-1979	2 (6.0)	9 (6.3)	15 (6.5)
Winter Barley	9 (5.9)	3 (5.7)	1 (5.5)
Spring Cereals	7 (4.2)	5 (4.1)	1 (3.8)

Source: ADAS, Cambridge, 1980.

Trash burial is particularly relevant in the U.K. where straw incorporation is a major function of cultivation, because the burning of straw has been banned. McDiarmid (1992) reported that the mouldboard plough remains the most satisfactory basic cultivation implement in the U.K. to incorporate straw. The plough provides high work rates and the ability to bury trash effectively. It can operate on different types of soil in wet weather and can often crumble the soil to a significant extent. At the present time, a farmer is able to choose from a range of mouldboard types enabling a choice to be made to suit the prevailing soil conditions.

Furrow pressing is a secondary cultivation operation designed to speed up seed-bed production and generally, it is done at the time of ploughing. Ansell (1986) cites Giro-Renedo (1985) as being the first recent work to study furrow presses. Today, they are widely used to crush clods, give fairly uniform consolidation of soil and help to conserve moisture in the seed-bed. Ansell commented that on light soils the furrow press 'is established as an integral part of the plough'. In recent years, many farmers have started to use furrow presses on heavy soils to minimize moisture loss from the ploughed land.

Work was carried out by ADAS, Reading (1983) to study the effect of incorporating straw on soils. They found that from trials on straw disposal, which were carried out for many years at Rothamsted, improvement in soil structure was about 0.1% increase in soil organic matter from incorporation of straw, also they advised to avoid a layer of straw at plough depth by discing long unchopped straw before ploughing.

Chamen and Cope (1992) investigated the establishment of a crop directly into both stripped and chopped straw. Results from four years of trials shows that rolling the stripped straw prior to cultivation can help the effectiveness of this process considerably and that the plough should be used afterwards in the same direction as the roll.

The disc harrow can incorporate chopped and stripped straw successfully after rolling, the discs being used at right angles to the direction of the roll. Pre-mixing with discs can improve the tilth produced by the plough and therefore ease seed-bed preparation on heavy soil. Also they found that stripped straw decomposed as quickly as chopped straw (65% decomposed after one year). In the presence of straw, slugs and some cereal diseases can increase and additional chemicals may be needed to provide control.

The work reviewed above (1.9.1 to 1.9.6) has been performed in the U.K. where particular problems include the cultivation of heavy soils, high moisture contents and the burial of surface trash, particularly straw. The research will be related to that completed under different conditions, but in a similar context in North African countries, particularly the Sudan and Morocco in Parts I and II.

PART ONE - THE SUDAN

2.0 LITERATURE REVIEW

2.1 Location - Sudan

Sudan is the largest African state, covering an area of nearly one million square miles. It shares borders with Egypt and Libya to the north, Ethiopia and the Red Sea to the east, Kenya, Uganda and Zaire to the south, Chad and the Central African Republic to the west.

The Nile, the largest river in the world (6671 km) runs through the country from south to north. Sudan has a population of about 22 million and the capital, Khartoum, is situated at the confluence of the Blue and the White Nile (**Figure 2.1**).

2.2 The Wheat Subsector Of Sudanese Agriculture

Before World War II, all wheat produced in the Sudan was cultivated under irrigation along the banks of the River Nile north of Khartoum. Wheat was also consumed mainly in the northern region until the 1960s, when consumption began to spread to other parts of Sudan (Salih, 1983).

Wheat was first introduced in the central clay plains of Sudan, south of Khartoum, in 1942 on about 5000 ha in the Gezira Scheme. However, production was discontinued in Gezira from 1947 to 1959 because of poor yields, high production costs, and competition with cotton for labour for harvesting. Wheat production in Gezira was revived on 2100 ha in 1959 after promising yield results were obtained on the Gezira Research Farm (Hassan and Faki, 1993).

Figure 2.1 Sudan: Regions

Since then the land under wheat in the central plain of Sudan has increased substantially, especially in the Gezira - Managil and New Halfa Schemes, although climatic conditions in these schemes are less favourable for wheat production than conditions in the northern part of the country.

2.3 Wheat Self-Sufficiency Strategy

Wheat consumption has grown tremendously in Sudan through food aid in the form of wheat, high consumer subsidies, and rapid urbanisation (Damous 1986; Bickersteth 1990; Hassan *et al* 1991), **(Figure 2.2)**.

In early 1990, the government of Sudan launched a crash programme to promote domestic wheat production and to bridge an increasingly unsustainable gap between local supply and consumption. The main objectives of Sudan's new domestic wheat supply strategy are to reduce the reliance on imported food and to reduce foreign exchange expenditure on wheat imports. However, expanding local wheat production leads to greater competition for scarce agricultural resources between wheat and alternative crop enterprises, especially cotton, that are important foreign exchange earners for Sudan.

The foreign exchange resources saved by substituting local wheat for imported wheat therefore need to be compared to the opportunity cost of the domestic and foreign resources required to support local wheat production, (or foreign exchange foregone as a result of reduced production of export crops). The expansion has been at the expense of cotton and other crops. For example, the cotton area in the Gezira has declined by more than half since 1987 **(Figure 2.3)**.

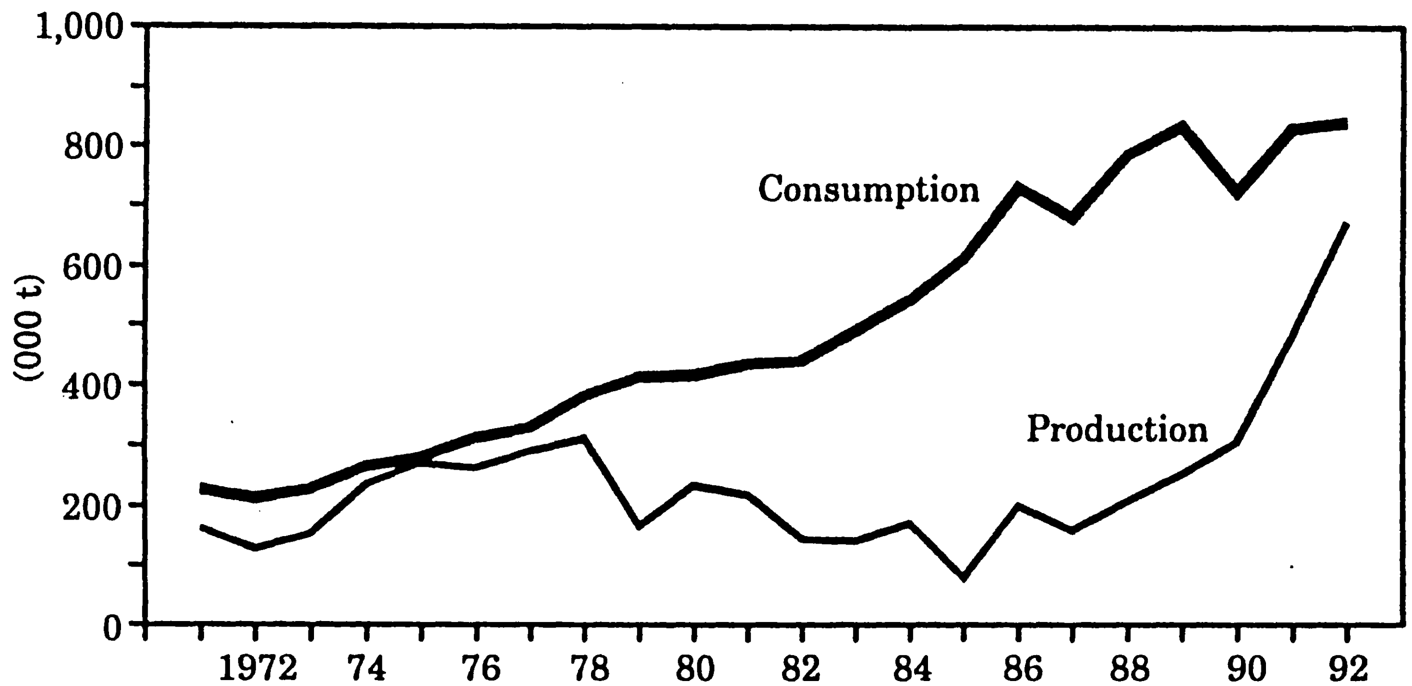


Figure 2.2 Trends in total wheat production and consumption, Sudan, 1971-92

Source: Ministry of Finance and Economic Planning *Economic Survey* (various issues).

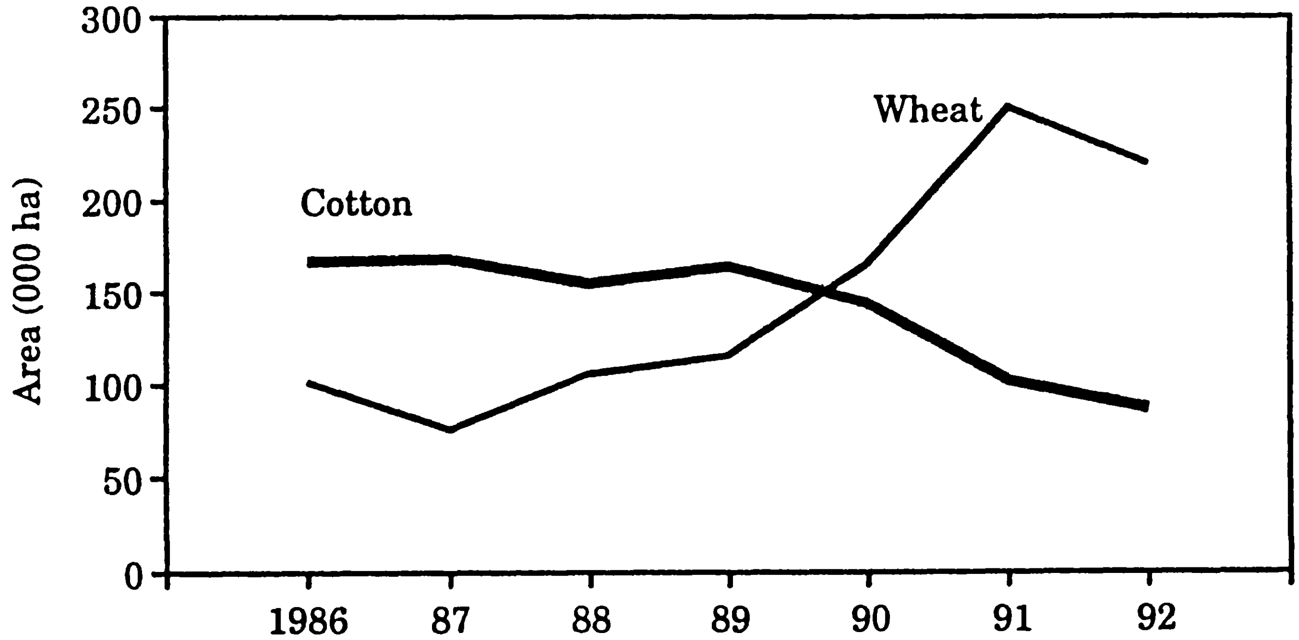


Figure 2.3 Area sown to wheat and cotton in the Gezira Scheme, Sudan, 1986-92

Source: Sudan Gezira Board, *Annual Report* (various issues)

[2] Although average wheat yields in Gezira reached their highest levels ever in 1991-92 (**Table 2.2**), the wheat season that year was abnormally cold. Thus in assessing the yield potential of wheat in Gezira, 1991-92 was excluded as atypical.

In addition the government strategy aims to exploit the potential gains from improved wheat production technology developed by the Agricultural Research Corporation (ARC) to fill the gap which remains between potential yields and the yields obtained by farmers.

Information from research on irrigated wheat production in the Gezira area prior to the 1980s is very limited.

In early 1990, the Sudan government banned the importation of wheat into the country making the growing of wheat in the Sudan more necessary to meet the demand for it.

2.4 Review of Crop Production in the Gezira

From 1925 to the early 1930s, a 3-course rotation growing cotton - Sorghum/Lubia and a fallow leg with 66% crop intensity was followed.

In the second stage, from 1933 to 1960, the rotation was widened to become 8-course, with 50% crop intensity. This was found necessary to help control bacterial blight disease in cotton (black arm) and to maintain land productivity.

The third stage was the intensification stage when wheat and ground nuts were introduced in the 8-course rotation from 1961 to 1974. Crop intensity was increased to 75%.

The fourth stage started in 1975 when vegetables were introduced in the ground nut/sorghum phase. The fifth stage started in 1986 when fodder crops were allowed a full leg in the rotation which became a 5-course rotation with 80% intensity as shown in **Figure 2.4 and Table 2.1** and the crop calendar, shown in **Figure 2.5.**

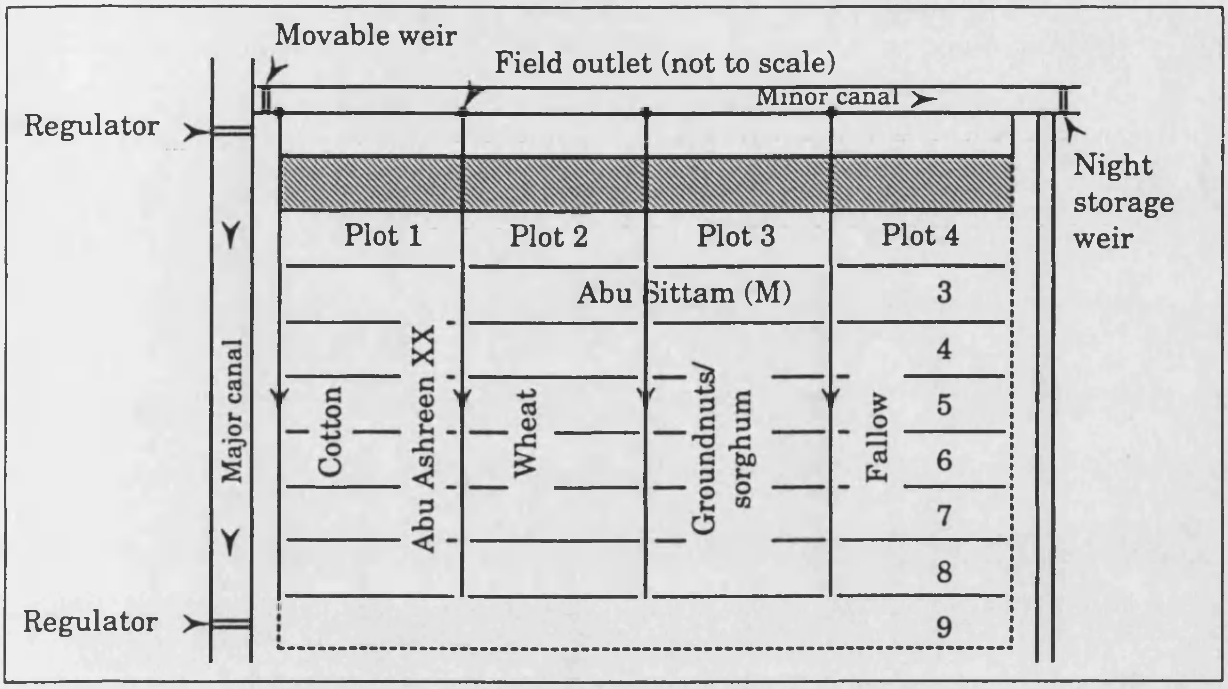


Figure 2.4 Typical field layout showing crop rotation and irrigation schedule, Gezira, Sudan.

Table 2.1 Crop rotation in the Gezira Scheme, Sudan

	Crop tenancies				
Year	**Plot 1 (2.1 ha)**	**Plot 2 (2.1 ha)**	**Plot 3 (2.1 ha)**	**Plot 4 (2.1 ha)**	**Total farm size (ha)**
Year 1	Cotton	Wheat	Groundnuts/ sorghum	Fallow	8.4
Year 2	Wheat	Groundnuts/ sorghum	Fallow	Cotton	8.4
Year 3	Groundnuts/ sorghum	Fallow	Cotton	Wheat	8.4
Year 4	Fallow	Cotton	Wheat	Groundnuts/ sorghum	8.4

Note: Although the groundnut/sorghum tenancy is mainly devoted to a combination of groundnuts and sorghum, at certain locations farmers are allowed to grow vegetables.

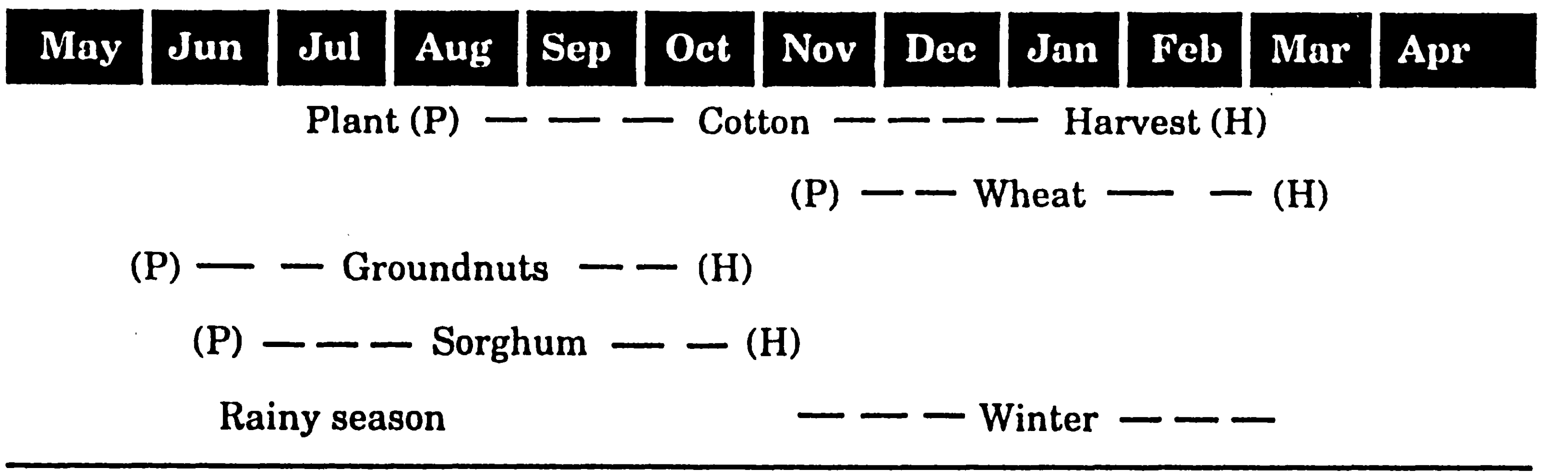


Figure 2.5 Crop calendar, Gezira, Sudan

The Managil extension started with a 6-course rotation in 1958 and continued until 1961 with 66% intensity of cropping. It was changed to a 3-course rotation in 1961 with 100% intensity; problems arose in the form of irrigation water shortage and heavy weed infestation. The rotation was changed to 4-course in 1989 by the inclusion of a fallow leg and then to a 5-course rotation by the inclusion of fodders in 1990.

2.5 Wheat Production Pattern

2.5.1 Wheat in the Gezira Scheme

The best potential for expanding wheat in Sudan exists in the Gezira Scheme and the most recent expansion in wheat production has occurred there. Wheat area in Gezira was 250,000 ha in 1991 compared to 106,000 ha in 1988, an increase of 136% (**Table 2.2**).

Although the wheat area has expanded substantially in the Gezira over the past four years, grain yields have been disappointing (1.36 t/ha) as shown in **Figure 2.6a** and **2.6b.**

2.5.2 Wheat Establishment Problems

A number of practices, including land preparation operations, seed rate and sowing date influence crop stand and yields. Precision in land preparation operations, especially in levelling land is critical for uniform plant growth, optimum plant population and avoidance of waterlogging to which wheat seedlings are very sensitive (Ishag *et al*, 1991).

Table 2.2 Wheat self-sufficiency and the contribution of the Gezira Wheat to the domestic supply, Sudan, 1971-92.

Season	Gezira wheat area (000 ha)	Gezira wheat yield (t/ha)	Gezira contribution to domestic supply (%)	Self-sufficiency (%)
1970-71	59	0.95	35	72
1971-72	55	1.03	44	61
1972-73	61	0.99	40	67
1973-74	107	1.08	49	89
1974-75	180	0.96	64	96
1975-76	238	0.88	80	84
1976-77	212	1.28	94	88
1977-78	196	1.12	70	82
1978-79	207	0.60	75	41
1979-80	152	1.12	73	56
1980-81	154	0.49	35	50
1981-82	113	0.78	62	32
1982-83	65	1.42	66	29
1983-84	112	0.93	62	31
1984-85	.. [a]	.. [a]	0	13
1985-86	101	1.20	61	27
1986-87	76	1.20	58	23
1987-88	106	1.34	69	26
1988-89	115	1.54	71	30
1989-90	165	1.44	78	42
1990-91	250	1.10	57	58
1991-92	220	2.10	69	80

Source: Ministry of Finance and Economic Planning, *Food Security Study* (1988); Ministry of Finance and Economic Planning, *Economic Survey* (various issues); Ministry of Agriculture, *Agricultural Statistics* (various issues); and Sudan Gezira Board, *Annual Report* (various issues).

a No wheat was planted in 1984 in Gezira because of severe water shortages caused by the drought.

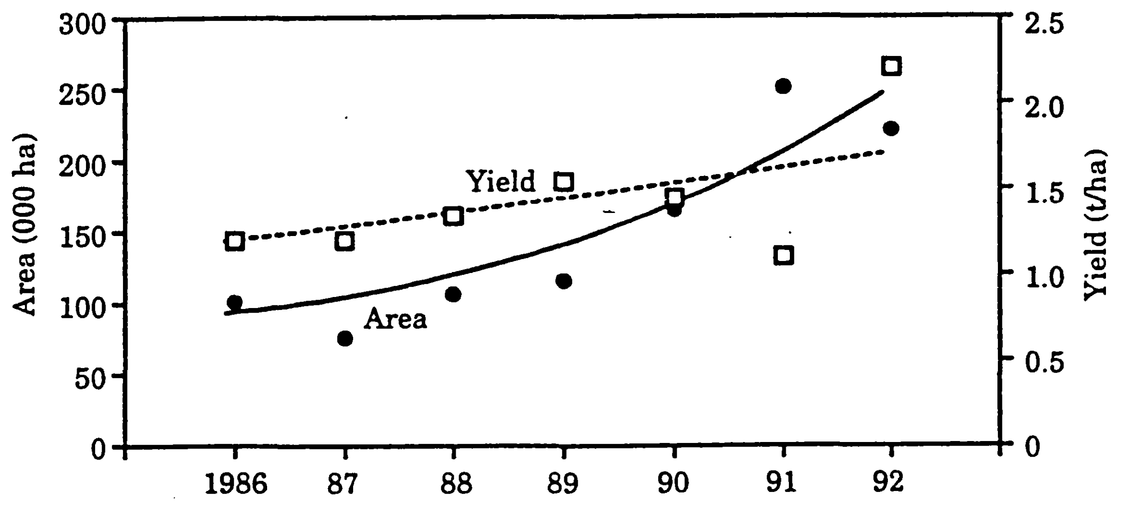


Figure 2.6a Exponential trends in wheat area and yield in the Gezira Scheme, Sudan, 1986-92

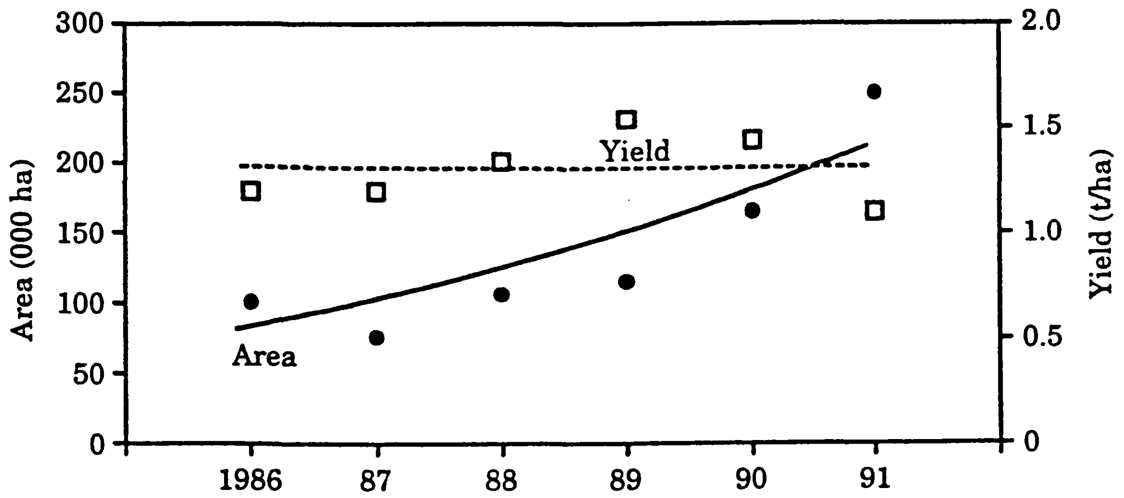


Figure 2.6b Exponential trends in wheat area and yield in the Gezira Scheme, Sudan, 1986-91 (1992 excluded as exceptional).

Under Gezira conditions a survey conducted in 1985-86 (Faki and Abel Fattah 1986) showed that the degree of levelling and the presence of patchiness and weeds were important factors affecting wheat yields.

Babiker *et al* (1991) studied the major causes of poor establishment of wheat crops on the clay soils of the central area of the Sudan. Main factors included:

- Inadequate land preparation including field levelling.
- Excessive water application at planting time.
- Inadequate seed depth which leads to the seed being washed out by the applied water, failure to germinate due to excess water (flooding during the first watering) and lack of sufficient moisture due to uneven field levels.
- Damage by predators, particularly termites and birds.

2.6 Factors Influencing the Establishment of Wheat in the Semi-arid Area of the Gezira

2.6.1 Soils

The Gezira plain constitutes part of the central clay plains of the Sudan being classified as predominantly vertisols. Willcocks and Browning (1986) from Overseas Division, AFRC Institute of Engineering Research at Silsoe, studied vertisols ('black' cracking clays) in the Sudan. They cite Coleman (1950) who found that this type of soil (60% clay fraction) had an infiltration rate of approximately 2.5mm per hour.

Total penetration of water was limited to 0.6m, except where deep cracking had resulted from land drying out over a long period. However, they also cite Spoor (1963), who found that on Shambat Vertisols, final infiltration rates in furrow irrigation were 1-4mm per hour. At the Gezira Scheme on 'black cotton soils' they cite Ahmed (1984) who found that the soil dries completely and large cracks develop. Therefore irrigation at two-week intervals is recommended, although some degree of flexibility in intervals is possible without loss of yield. Singer (1987) who evaluated the semi-arid land conditions of the Mediterranean countries, cites Virmani *et al* (1982) who commented that vertisols of Australia, India, Sudan, Chad and Ethiopia are very difficult to manage because of their particular characteristics.

Craig (1991) in his book about the Agriculture of the Sudan commented on the Gezira soils, stating that "the vertisols are deep, dark-coloured, low in organic matter, very slowly permeable when wet, deeply cracked when dry and the clay content is 50-60%". The soils of Sudan are shown in **Figure 2.7.**

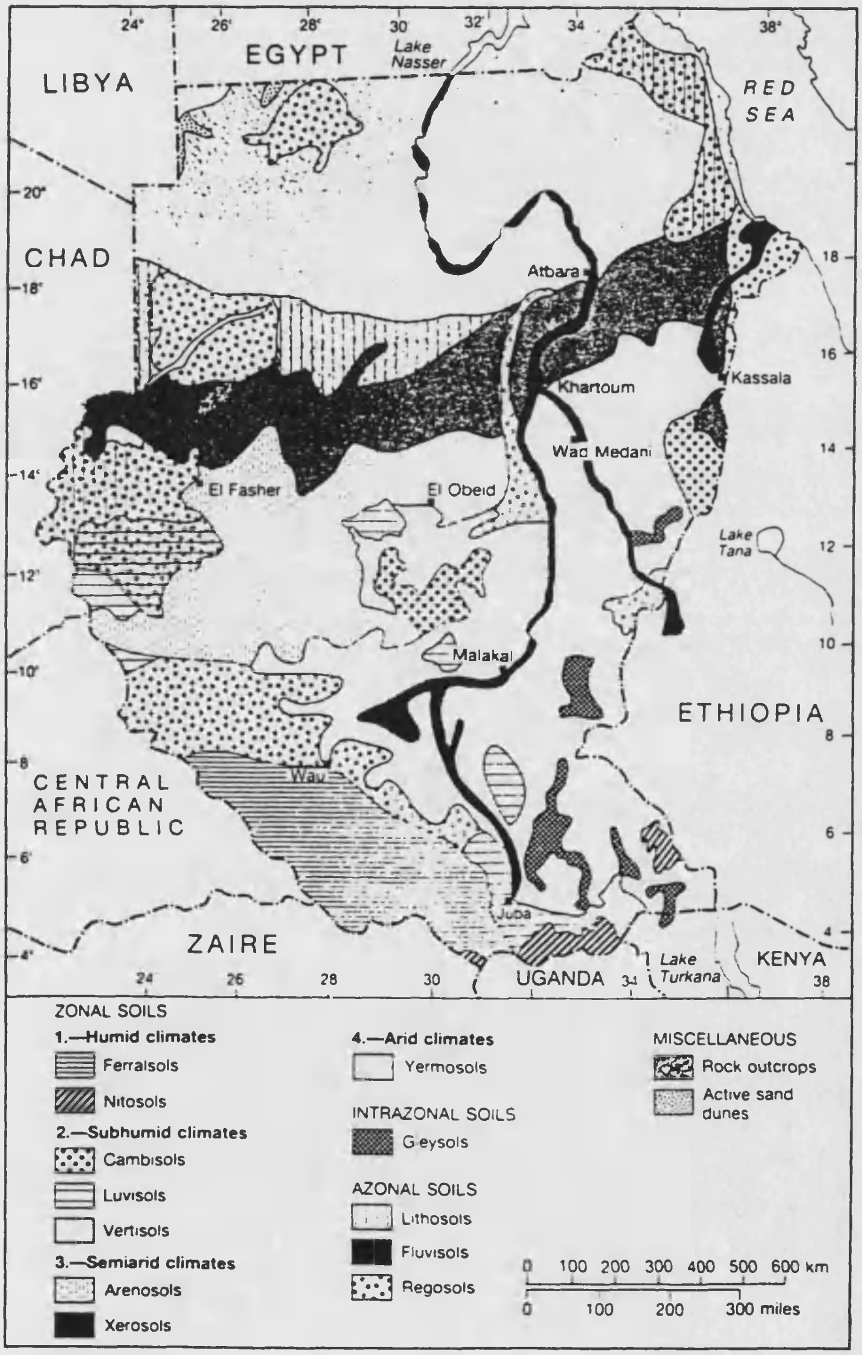


Figure 2.7 Sudan Soils (FAO, UNESCO 1973)

2.6.2 The Environment

The climate of the Sudan ranges from desert in the North, tropical semi-arid and sub humid with a short summer rainy season in the central area, to tropical wet-dry and tropical rainy types with a progressively longer wet season in the South. Summary characteristics of each climatic type are shown in the Appendix (**Table 1 and Figure 1**).

The Gezira Scheme lies within the semi-arid zone of the Sudan (**Figure 2.8**). It is characterised by a long dry season which is generally warm with cooler nights. Before the onset of the rainy season and during the months of May and June, ambient temperatures progressively rise and relative humidity increases. The months of July and August contribute about 2/3 of the total annual precipitation. The Gezira area lies between isohyets 200 mm and 450 mm per annum.

2.6.3 Irrigation System

The irrigation system of the Gezira and its south-west extension (Managil) utilizes water from the Blue Nile in accordance with the Nile Water agreement between Sudan and Egypt.

The Sennar dam raises the level of the water so that it flows under gravity into the Scheme (**Figure 2.9**). The dam itself has a length of 3025 m and has sluices 8.4 x 2m wide each fitted with heavy steel gates. Spillways are also incorporated and regulators admit water into the main canals. The gravity irrigation system in the Gezira Scheme provides irrigation water more cheaply than the pump system used in the north.

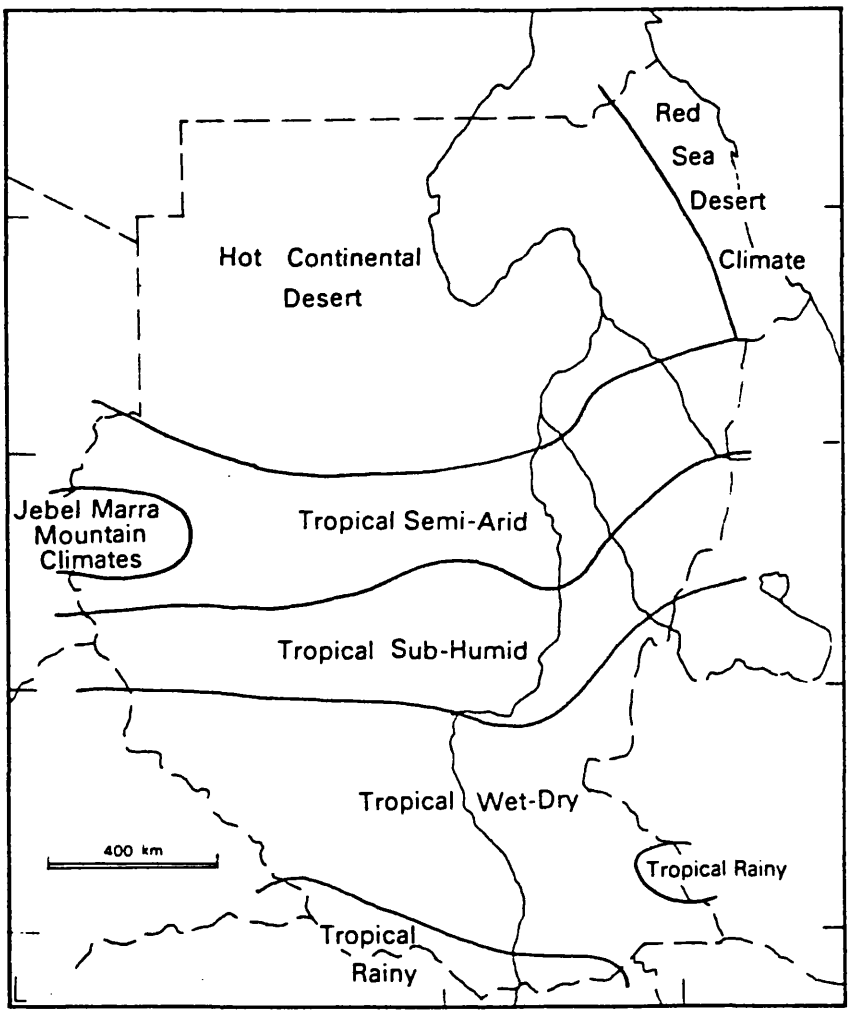


Figure 2.8 Sudan Climatic Regions

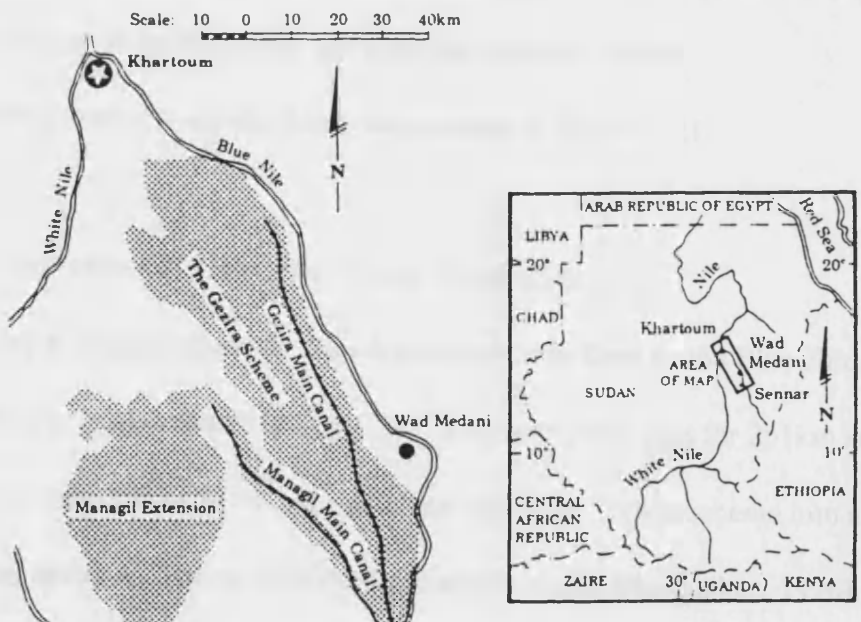


Figure 2.9 Location of the Gezira Irrigation Scheme, Sudan

2.6.3.1 Flooding Irrigation Layout

The standard Gezira irrigation layout is schematically represented in **Figure 2.10.** The water ditches Abu XX are fed from a minor canal through a field outlet fitted with adjustable gates at the upstream end. The field outlets vary with the land levels, this variation together with variation in flow in the channel produces variation in discharge. This capacity of AbuXX is to take 10,000 m^3/day Each AbuXX carries water for 90 feddans.

2.6.3.2 Watering System

Abu XX feeds field laterals called Abu VI through steel pipes. Each Abu VI is 280 m long and irrigates 5 feddans. A system of seven smaller channels (gadwals) separated by eight borders (tagnets) facilitates the spread of water over each field (Hawasha). Approximately 400 m^3 of water are needed to irrigate a feddan; thus it takes about a week to irrigate 90 feddans from one Abu XX (Ahmed, 1989).

The watering system is schematically represented in **Figure 2.11.**

2.6.3.3 Irrigation Practices for Wheat Production

Water is fed to Gezira by gravity flow from the Sennar Dam on the Blue Nile through a network of irrigation canals (**Figure 2.9**). The main canal runs for 261km and delivers water from the source at the southern end of the Gezira scheme into a distribution network of about 150,000km of minor canals (Plusquellec, 1990). This indicates the long distance water has to travel to reach many farmers at remote locations in Gezira.

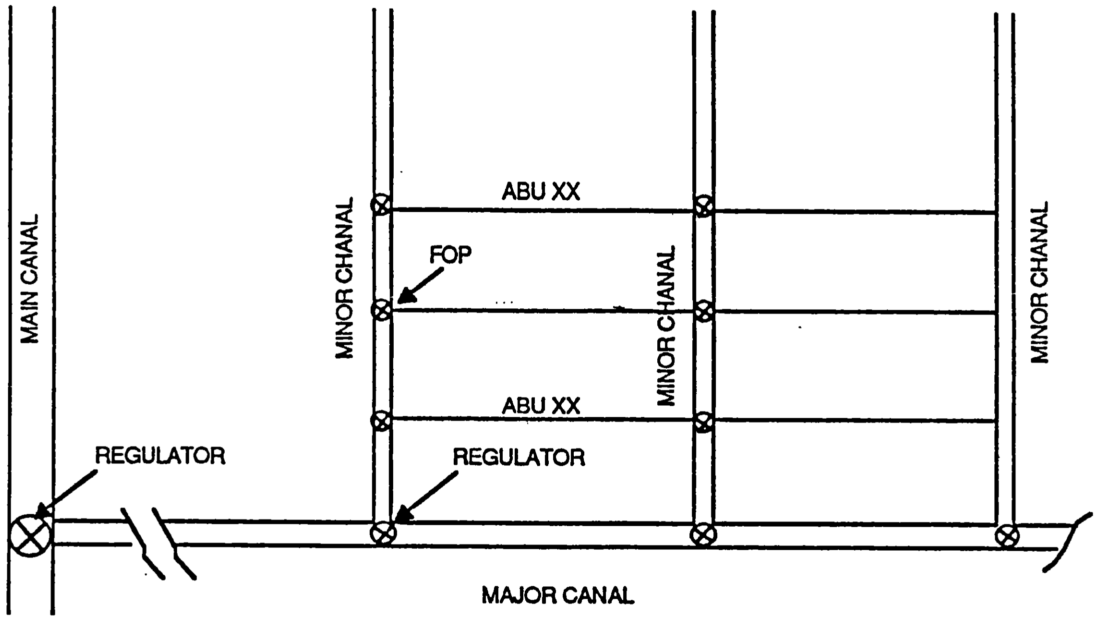


Figure 2.10 Field Layout Gezira Standard

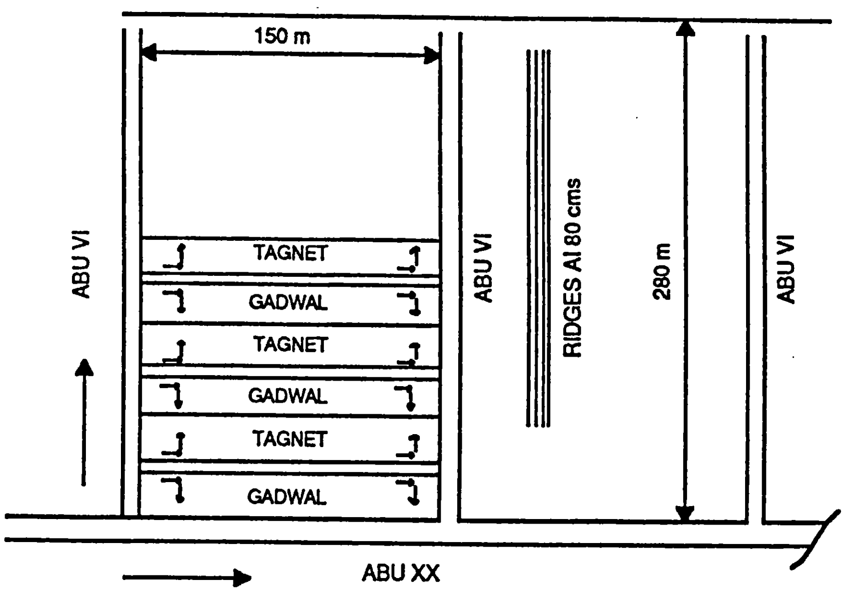


Figure 2.11 Watering System

The research recommendation is that irrigation should be applied every 10 days during the vegetative stage and every 14 days during flowering and grain filling for a total of seven to eight irrigations (Ageeb, 1991; Ageeb 1992; Ishag *et al*, 1991). In practice, water supply problems keep the number of irrigations well below the recommended number. For some control of irrigation, a 2.1 ha (Hawasha) wheat field should be divided into 56 small basins. Fields with large basins are common, and farmers often allow water to flow into the field unattended, sometimes at night. Faki and Abdel Fattah (1986) carried out a field survey in the Gezira Scheme, showing that farmers who applied an average of 7.8 irrigations obtained yields 23% higher than the average in the Gezira, obtained with an average of 5.7 irrigations, and 43% higher than yields obtained under 4 irrigations. Another experiment at the Gezira Research Station indicated that a profitable yield increase of 750 kg/ha could be obtained with the application of 8 versus 5 irrigations (Ageeb *et al*, 1986).

In the final report on the Sudan Gezira Rehabilitation Project, the consultants comment on Long Furrow Irrigation as an alternative to the present irrigation system. They report that: experiments in the Faculty of Agriculture, University of Khartoum, Research Corporation, Wad Medani and the Agricultural Engineering Department of the Gezira Scheme have been carried out. Experiments at Shambat (G. Spoor, 1963) showed that 150m furrow length was the optimum in clay soil. Longer furrows would enable longer tractor runs and reduce implement turning time, but they necessitate more precise and expensive land levelling.

The adoption of Long Furrow Irrigation requires that levelling of fields is undertaken.

Using an automatic planer once or even twice if need be will still prove cheaper than rebuilding the field ditches and embankments of the present system. The area saved by using this method is about 15% of the field area.

In the 1989/90 season, the pilot farm ran a trial on Long Furrow Irrigation in collaboration with the University of Gezira, but no result has yet been published (M.C.E.S.P.A. and Tanmiah, 1991).

2.6.4 Seed-bed Preparation and Sowing Methods

On the heavy clay soils of the Central State of the Sudan, the different methods of land preparation, sowing and irrigation affect wheat establishment and directly cause low yields. Generally early seed-bed preparations are started in August to control weeds during autumn and roughly prepare the land surface; rain water assists in making the operations easier. Conservation of some moisture can be achieved by using various cultivation implements as available.

2.6.4.1 The Recommended Tillage System

The tillage system recommended by The Agricultural Research Corporation (ARC) in Wad Medani is first disc harrowing during the rainy season. During September to October, at the end of autumn, a second cultivation would be done, again using a disc harrow. When the soil has a reasonable moisture content after the autumn this should be followed by a levelling operation. Mechanical planting is recommended using conventional seed drills or wide level disc type drills at 50 kg/f seed rate under the Gezira conditions. This system will be used as the control treatment as part of the experimental programme.

2.6.4.2 Sowing Dates and Seed Rates

The researchers of the ARC at Wad Medani have carried out extensive work on the sowing dates of the wheat crop. Ageeb,(1992); Elahmadi *et al*, (1993) have recommended that the sowing date for wheat is set between 12th and 26th November and that a seed rate of 50 kg/f is used. However, recently most farmers in the Gezira scheme have increased the seed rate to 60 kg/f, thinking that this would improve establishment and lead to higher yield.

2.6.4.3 Pre-sowing Watering (PSW)

The technique of pre-sowing watering has been developed to encourage wheat establishment under cracky heavy clay soils in the Sudan. However, there is still the need to reduce the problems caused by the lack of levelling which arise when irrigation is applied, particularly for the first time watering after sowing which is generally critical and not spread evenly when the levelling is not done properly. In addition on heavy clays in the Gezira and with pre-sowing watering, it will be hard for sowing machinery such as wide level disc and seed drills to work in the messy conditions, especially when the soil is too wet and much heavier (high percentage of clay 55-60%). Comprehensive research work has been carried out in the last three years within the different research stations to study land preparation for the wheat crop. Babiker *et al*, (1991) studied the different factors of wheat crop establishment to seek solutions for improving poor crop establishment under Gezira and Rahad conditions.

Factors studied included land preparation and sowing methods for better application of irrigation water, adequate seed placement to avoid washing out during the first watering and to reduce the damage caused by termites.

In the Gezira, the effect of PSW on grain yield was very highly significant with increases up to 35% (**Table 2.3**). At Rahad PSW increased grain yield by up to 32% (**Table 2.4**). The main reasons for the increases were the greater number of heads per unit area, reduced weed infestation and reduced termite damage. Also the time needed for irrigation was shorter when PSW was used. It may be that the large amount of water required for PSW is not always available due to the irrigation of other crops and also that during this time, shortage of water is sometimes experienced. The Ministry of Irrigation and Water Resources restricts water applications during the summer season.

Satti, (1992) carried out two experiments on cracking soils at Umger and Abassya in the central area of the Sudan. He studied three traditional land preparation methods for wheat.

The seed (Condor) was broadcast on flat land and the fields irrigated by flooding irrigation. He found no significant differences in grain yield at either site, but Abassya was slightly higher in yield, the average being 2476 kg/ha.

It seems that this average grain yield was high compared with current yields and this was due to the favourable conditions for wheat production in 1992.

Babiker *et al* (1991) studied the effect of three sowing machines (two types of seed drill and broadcasting) and two methods of seed bed preparation (chisel plough, disc harrowing and levelling and disc harrowing only). The first seed drill was provided with tine furrow openers which placed the seed at an average depth of 6 cm. The second one provided a disc covering device which placed the seeds at an average depth of 4 cm. A broadcasting machine put the seeds on the surface and was followed by a light disc harrowing to bury seeds at depths ranging between 0-6 cm.

Table 2.3 Effect of pre-sowing watering on yield and yield components of wheat as average of eleven farmers in the Gezira Scheme (season 1989/90).

Pre-sowing Watering	Grain yield (t/ha)	No. of Heads (m^2)	No. of Grains/ Head	1000-grain wt (g)
Present	2.60	478	29.0	37.6
Absent	1.70	389	27.0	37.0
S.E. ±	0.145	0.056	0.201	0.321
Sig.Level	***	*	N.S.	N.S.

* = Significant at P = 0.05 *** = Significant at 0.001. N.S. = Not Significant

Source: A.A. Salih.

Table 2.4 Effect of pre-sowing watering on yield, yield components, number of weeds, and period of irrigation in wheat cv. Debeira in Rahad (season 1989/90)

Pre-sowing Watering	Grain Yield (t/ha)	No. of Heads (m^2)	No. of Seeds/ Head	No. of Weeds (m^2)	1000-grain wt. (g)	Termite damage (%)	Time of irrigation (days)
Present	1.88	381	30.1	5.0	41.0	5.8	1.7
Absent	1.42	359	29.9	11.7	42.0	7.9	3.0
S.E.±	0.102	0.76	0.76	0.86	0.41	-	040

Source: Babiker and Kannan.

Table 2.5 presents the performance of the three sowing methods and shows that sowing with the first seed drill (with tine furrow openers) gave the highest grain yield, outyielding the other two machines by 25 and 28% respectively.

They commented that the effects were due to the different depths of sowing, and the differences in the number of plants per unit area, especially in the case of preparing the seed-bed with disc harrowing only.

Broadcasting of seed under the Gezira conditions tends to be unsatisfactory, particularly because of bird damage, even when the broadcasting operation is followed by disc harrowing; also for broadcasting, a higher seed rate is required (up to 180 kg/ha) and many farmers find a need to re-broadcast after 2 or 3 weeks due to the failure of the crop to establish.

The two methods of land preparation did not affect the number of plants per square metre significantly at emergence.

Ageeb (1991), working on heavy clay soils of the Gezira found that the number of plants per m^2 is a major factor for successful wheat establishment. Operation costs indicated that land preparation with disc harrows only cost less and had a higher work rate compared with other methods of seed-bed preparation in the experiments conducted.

Table 2.5 Effect of three sowing machines and two land preparation methods on yield of wheat cv. Debeira in Rahad Scheme (season 1989/90)

Method of land preparation			
Chisel plough + harrowing + levelling		**Disc harrowing**	
Grain yield (t/ha)			
Method of sowing		**Mean (+ 0.069)**	
Drill A	1.15	1.12	1.14
Drill B	0.88	0.85	0.86
B.C.	0.74	0.90	0.82
Mean	0.92	0.96	
No. of plants/m^2			
Drill A	193	190	191
Drill B	190	179	184
B.C.	196	185	191
Mean	185	185	

Source: Omer and Babiker.

B.C. = Broadcasting.

Significant at P = 0.05

Another researcher at Sennar Research Station (Omer, 1992) studied the effect of pre-sowing watering on wheat establishment using the wheat variety Debeira at a seed rate of 60 kg/f on four fields of 5 feddans (2.1 ha). Treatments included twice disc harrowing as The 'Recommended Tillage System'. Two fields were flooded 27 days before sowing (more than field capacity). The other two were left dry. A wide level disc was used for planting. Fertilizers were applied at sowing time.

Results indicated a significant increase (at the level of P = 0.05) in grain yield (27.7%) following pre-sowing watering. However, there were no significant differences in grains per spike or 1000-grain weight.

It seems that on heavy clay soils of the central area of the Sudan that precision levelling is required to control the spreading of irrigation water evenly over the field especially the first watering after sowing which has a great effect on the number of plants per m^2, and therefore the grain yield (Ageeb and Mohamed, 1990).

Further experiments need to be carried out using different methods of seed-bed preparation, (ridges and beds) which could control the irrigation water at the required amount and avoid the problem of inadequate seed depth which leads to flooding washing seeds out during the first watering, or lack of moisture causing failure to germinate. Better seed-bed preparation would also encourage germination and emergence.

2.6.5 Soil Physical Properties

Mohamed Ali (1991) from Gezira University studied the effect of conventional tillage, minimum tillage and sub-soiling tillage on some soil physical properties with cotton (*Gossypium barbadence* L.) under Gezira conditions.

Three tillage treatments included disc harrowing to 7 cm depth as a minimum tillage. Disc plough with 3-bottoms to 15 cm depth followed by harrowing once as a conventional tillage. Sub-soiling to 50 cm depth followed by harrowing twice as deep tillage. In all treatments 80 cm ridges were made to plant cotton. The study examined bulk density to 90 cm depth following the same technique as Blake and Hartge (1986). The results agreed with the fact that changes in bulk density depend on the amount of soil loosening done (Soane, 1975).

The results showed that the upper depths for all treatments have bulk densities which were not significantly different, and this was probably due to the rainfall and flooding irrigation which recompacted the soil.

At all depths, deep tillage had the lowest bulk density followed by conventional and minimum tillage. This may have been due to soil loosening at these depths, **(Table 2.6)**. This agrees with the results found by Soane (1975) and is supported by the findings of Burnett and Tackett (1968) that 4 years after rototilling and 3 years after mixing with a ditching machine, the bulk density of the loosened soil was still lower than at similar depths in conventionally-tilled plots.

Infiltration rate was determined before treatment application and at the end of the season using a double ring infiltrometer as described by Landon (1984). Cultivation increases the infiltration rate of crusted and compacted soil (Baver *et al*, 1972).

Table 2.6 Effect of tillage on dry bulk density (gm/cm^3)
(28 weeks after sowing)

Depth (cm)				
Treatments	**0-15**	**15-30**	**30-45**	**45-60**
Minimum Tillage	1.07 a	1.11 b	1.42 c	1.46 a
Conventional Tillage	1.04 a	1.18 b	1.40 c	1.44 ab
Deep Tillage	1.05 a	1.09 b	1.31 c	1.36 bc
S.E. ±	0.02	0.04	0.03	0.03
C.V.%	4.7	8.9	6.16	5.76

Means within the same column having the same letter are not significantly different at P = 0.05 according to Duncan's Multiple Range Test.

The infiltration rate under conventional and deep tillage was 15.6 and 17.6 cm/h for the first five minutes infiltration respectively, and 20 cm/h at the beginning of the study before tillage treatments were applied. The high initial infiltration rate for untilled plots may be attributed to the cracks which lead to fast water movement through the soil. After 5 hours the infiltration rate for minimum tillage, conventional tillage, deep tillage and untilled plots were 0.75, 0.8, 1.03 and 0.6 cm/h, respectively. These results gave evidence that tillage operations increase infiltration, most probably because of soil loosening.

This also agrees with the findings that subsoiling to more than 45 cm depth improved infiltration (Swain, 1975; Schindler and Muller, 1987).

The study involved the measurements of growth developments of root and shoot on different tillage practices for cotton plants during the growing season which are shown in **Figures 2.12 and 2.13.**

Another researcher, Mohamed Ali (1991), carried out experiments at the University of Gezira Farm, Nisheshiba, Wad Medani, to study the effects of soil surface disturbance by different implements on some soil physical properties and crop performance of butterfly pea (*Clitoria ternateà* L.) as a fodder crop, locally known as kordofan pea.

Tillage equipment used for land preparation included a mouldboard plough, a rigid tined cultivator, a standard disc plough, a disc harrow and no tillage. Soil bulk density was determined by the core sampler method (Blake, 1965 and Landon, 1984).

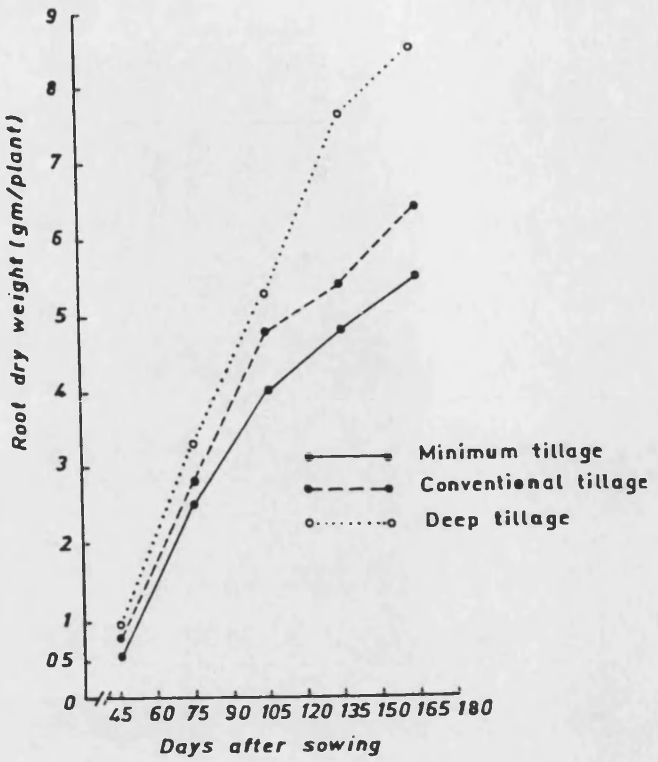


Figure 2.12 Effect of tillage on root dry weight.

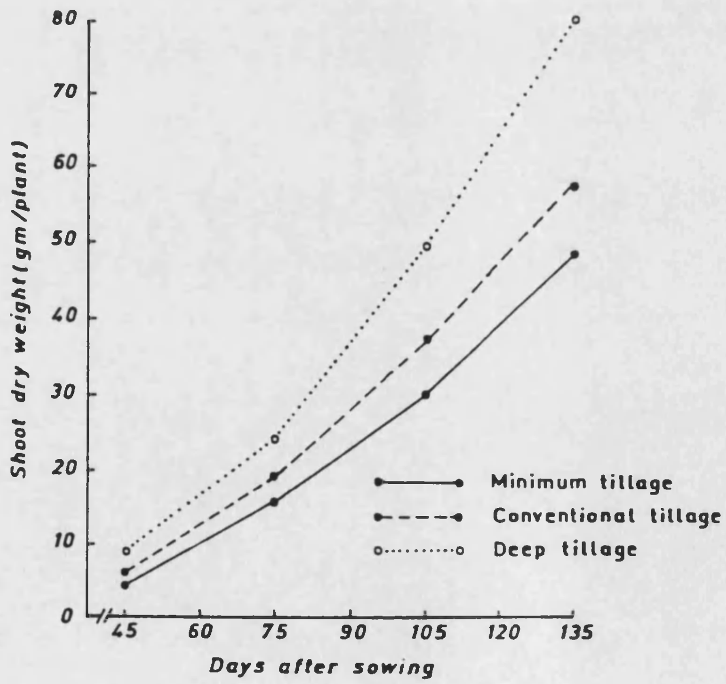


Figure 2.13 Effect of tillage on shoot dry weight.

Dry & wet bulk densities were measured before and after tillage treatments (**Figures 2.14 and 2.15**). Results obtained showed significant differences in both dry and wet bulk density values between different treatments within the measured depths of 0-35 cm range, except at 30-35 cm layer for dry bulk density. Tillage reduced the soil bulk density at different layers as compared to non-cultivated soils, although their values increase with depth. At the beginning of the growing season, the disc-ploughed plots gave the highest dry bulk density (1.47 g/cm^3) at 30-35 cm depth. The mouldboard ploughed plots and tine cultivated plots produced the lowest dry bulk density values of 1.44 g/cm^3 for each treatment. There was no significant difference in dry bulk density between the four tillage treatments below the depth of cultivation 30-35 cm depth. Sheikh (1977) reported similar results on sandy-loam soil.

The study involved also measuring the effects of different tillage systems on crop parameters which included root length and plant height during the growing season, shown in **Figure 2.16 and 2.17.**

2.6.6 Land Levelling and Drainage

Low lying areas, particularly in the Managil, are subject to flooding from rainfall and are usually places where planting in the lower fields is delayed because of wet soil conditions.

Precision land levelling is a relatively new concept in the Gezira (Ageeb and Mohamed, 1990). In general the levelling operation is by using a 'Camara' levelling device which is a locally made device consisting of a steel beam, dragged behind a tractor. The Camara has a harrowing effect, it breaks the large clods and achieves crude levelling with some firming to the soil surface (Dawelbeit and Salih, 1992).

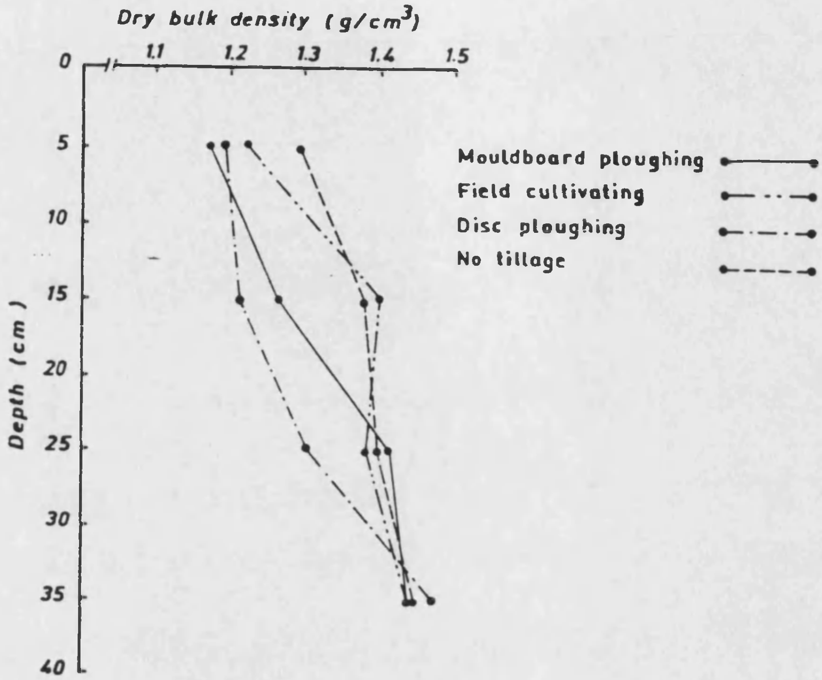


Figure 2.14 Effect of different tillage practices on dry bulk density of vertisols (at the beginning of the growing season).

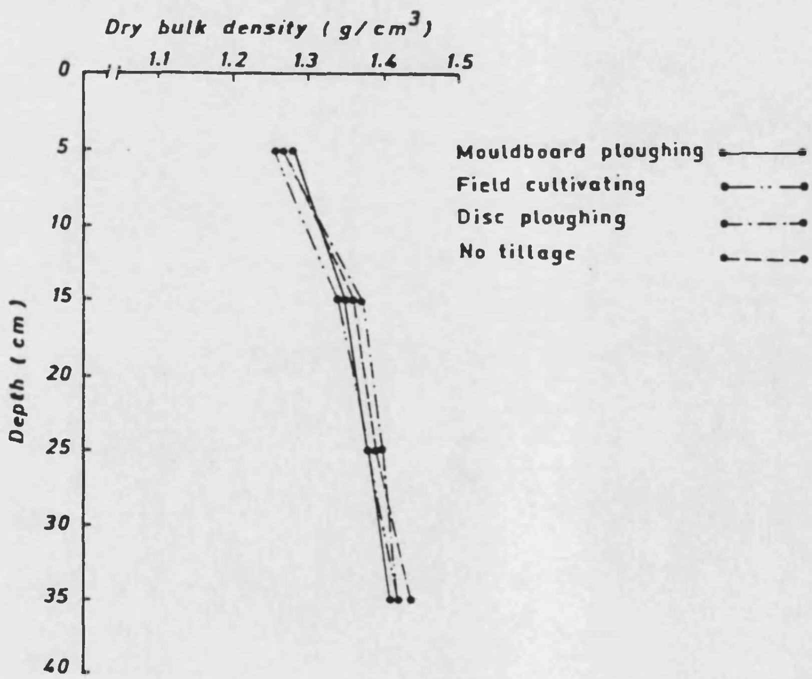


Figure 2.15 Effect of different tillage practices on soil bulk density after harvesting

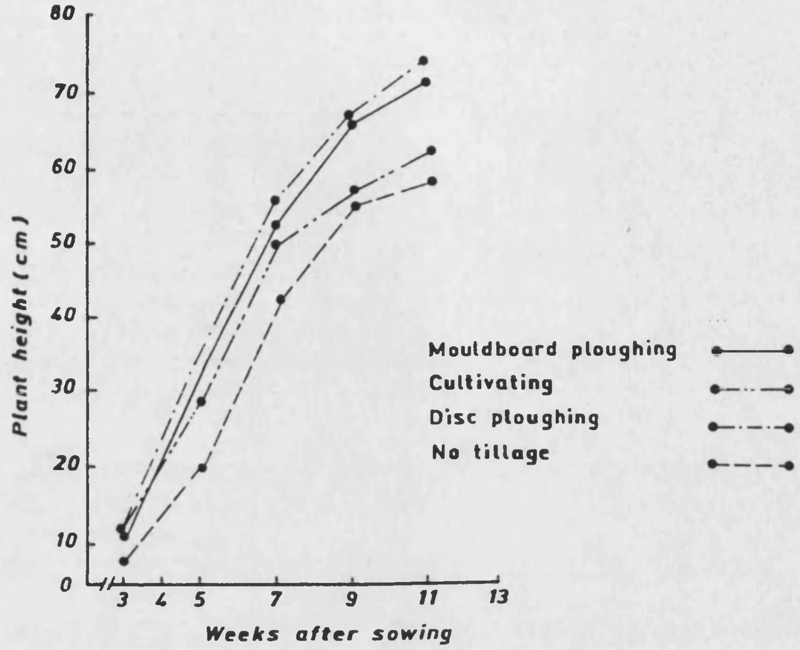


Figure 2.16 Effect of tillage practice on plant height

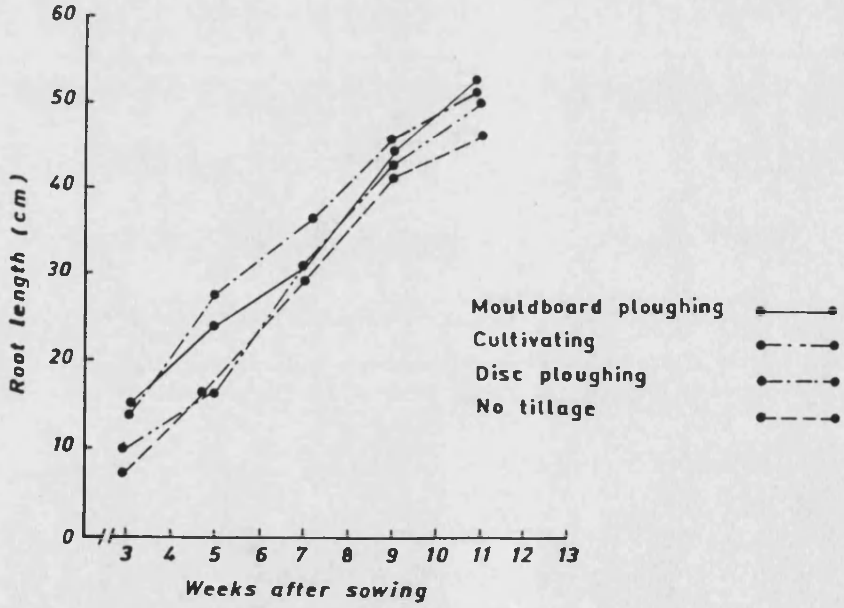


Figure 2.17 Effect of tillage practices on root length of Clitoria plants

In most cases at the Gezira the levelling operation is not done and the seed-bed is usually cloddy and uneven. This results in patchy seed distribution and uneven irrigation (Ageeb and Mohamed, 1990; Ageeb, 1991).

The basic drainage layout for the Gezira consists of a network of shallow drains along most minor canals linked to the major drains which discharge into the Blue Nile or low lying areas outside the Scheme (Pothecary, 1955).

2.6.6.1 Waterway Weed Control

Ahmed (1989) from the Hydraulic Research Station explained the different methods to deal with growth of weeds in the water ways through the irrigation network or drainage system as follows:

1. Manual

The Ministry of Irrigation employs labour to cut weeds in the minor canals manually, but the effectiveness of such methods is low and it has hazards, e.g. Bilharzia and cold water during the winter.

2. Mechanical

The dragline is used to clean canals by removing weeds and sediment. However, this method proved to be ineffective in the Gezira Scheme due to many reasons. One of these reasons is the total dragline capacity used in the Gezira Scheme compared to an area of 2.1 million feddans, approximately a quarter of that required. Moreover, the dragline is not capable of maintaining a minor canal without disturbing the profile of the bed and sides of the canal, this is happening in the Gezira Scheme now.

3. Chemical

Chemical control was used in minor canals to control weeds recently on a wide scale. It has many side effects, e.g. the health hazards associated with it, may kill livestock (animals and fish) and it may concentrate and cause chronic poisoning in humans. New environmentally acceptable chemicals are not yet available in the Sudan.

4. Biological

This is achieved in two ways as follows:

a) Grass Carp (fish) on submerged weeds.

b) The interception of daylight through trees and shrubs and by using plants with large floating leaves.

2.6.7 Application of Nutrients

Most farmers distribute fertilizer (Urea) by hand which often results in uneven and patchy distribution. This is reflected in uneven plant vigour and consequently areas with weaker canopy favour growth of noxious weeds (Babiker *et al*, 1992). The application of fertilizer is commonly delayed by the farmers up and prior to the second irrigation (Ibrahim *et al*, 1991).

Recommendations from research call for nitrogen in the form of Urea to be applied at a rate of 86 kg/ha at sowing or before harrowing. However, delays in providing fertilizer sometimes result in late application. The grain yield response to nitrogen is high, especially with high yielding cultivars. Using experimental station data, researchers estimated that optimum economic levels of nitrogen range between 79 and 105 kg/ha for the wheat cultivar Condor and between 88 and 112 kg/ha for the wheat cultivar Mexicani (Ageeb, 1992).

Other on-farm trials showed the application of nitrogen and phosphorus to be more profitable than the application of nitrogen alone (Ageeb, Mohamed and Faki, 1986). Phosphorus in the form of triple superphosphate is now recommended.

The field trials conducted under the Gezira conditions showed that a supplement of nitrogen on wheat, yielded positive results (Ageeb, 1992). The Recommendation of Urea rate is 86 kg/ha and 43 kg/ha triple super phosphate for the wheat cultivar Debeira to be applied at sowing or before the second disc harrowing on the Recommended Tillage System (Ageeb, 1992). Soils in Gezira differ in their nutritional status and thus require different levels of fertilizer application and nutrient mixes (Craig, 1991).

2.6.8 Control of Weeds, Pests and Diseases in the Wheat Crop

Prior to the drought years (1983-85) a light pre-watering was practised before the primary tillage operations in order to encourage weed emergence. This was considered an effective method of weed control. Currently, post rains, the first disc harrowing is used to encourage weed emergence. No post sowing weeding is practised and no herbicide use is currently recommended (Osman, 1993). Herbicide use is very limited due to high cost of provision and possibility of environmental pollution.

Although the general situation with respect to weeds under the Gezira conditions for wheat is not alarming, noxious weeds such as 'Adar' (*Sorghum sudanese*) or wild Sorghum is becoming increasingly serious in some areas and is controlled manually, Babiker and Mohamed (1991).

The only economically important pests in wheat in the Gezira Scheme are Aphids, but fields are only sprayed when the aphid population reaches the economic threshold. Normally no more than one or two aerial sprayings are applied (Sharafeldin, 1992).

The wheat crop in the Gezira is affected by termites but chemical control rarely practised. The traditional control method among farmers is to speed up the next irrigation which causes the termites to go deeper in the ground, under the wet level (Elmahi, Pers. comm., Kannan, 1992)

The Gezira area has been a "hot spot" for some diseases, mainly rust, both Stem Rust (*Puccinia graminis* f.sp. tritici) and Leaf Rust (*Puccinia recondita* f. sp. tritici).

Plant pathologists encourage their teams to make early observation in the field and to use chemical control to avoid any fast severe infection especially on susceptible varieties (Ahmed, 1991).

2.7 Agricultural Mechanization Considerations

Elhag *et al* (1992) carried out a study for rehabilitation of the Gezira Scheme, they found that Gezira has a very high degree of mechanisation compared to other production systems in the country. In recent years it is being realized that more mechanical operations, particularly in land preparation are required.

The key factors which need to be made available for mechanised production to be properly used are measurements of power used per unit area (using a popular tractor, such as 80 hp Massey-Ferguson) for different implements, the number of mechanical operations required per crop, rates of work of different implements and machines together with the associated costs of all the required operations for each crop involved in the rotation.

Most farmers are keen to cut their operating costs and believe in the concepts of minimal tillage which has been adopted for many years for mechanised rain-fed production in the Gedarif and Damazin areas.

In general, the operational costs of mechanisation are escalating at a very high rate. Also the difficulties of obtaining a regular supply of spare parts, the limited availability of proper maintenance facilities and competent machinery management add to the problems of mechanisation development. All these factors must be addressed before a fully workable scheme can be implemented.

2.8 Field Operation Costs

Mohamed, A.O. (1992) from the Rhad Irrigated Scheme surveyed the cost benefit of different tillage systems with light and heavy disc harrows in the central clay irrigated area for wheat production. He found that many farmers adopt different practices of seed-bed preparation believing that they might get better yields. Experimental operations were performed by public sector machinery within two groups of farmers selected from the scheme to record the operation cost and crop yields for different combinations of implements used. This study did not show the optimum depth of disc harrowing for wheat establishment under heavy soils and this needs to be determined.

Dawelbeit and Salih, (1992) from the Gezira Research Station surveyed the cost of four systems of land preparation using different tractors and disc harrows at the Gezira Scheme as follows:

	A	B	C	D
Tractors	75-130hp Wheeled	70-80 hp Wheeled	D5-120hp Crawler	75-150hp Wheeled
Type of Disc Harrow	Tandem & Offset	Offset	Offset	Offset
Cost (LS/ha)	797.3	464	725.9	797.3

The study analysed the performance of each system, its cost and effects on yield. They found that system B was the least cost. However, the highest yield was achieved with system D (2439 kg/ha) followed by system A (2303 kg/ha). These were most expensive systems but the authors interpreted that yield improvements were due to finer seed-bed and extra manipulation for shallow soil inversion which could be an advantage to the wheat establishment under heavy soils of the Gezira. The study did not include the exact depths of different disc harrows used with different tractor powers. The lower cost of system B was due to the saving in fuel consumption. Diesel fuel is expensive and not always available, particularly during the arable cropping seasons due to the high demand, transportation cost and infrastructure problems.

2.9 Research Situation in the Sudan

Over the past four years the wheat area has been expanded substantially but yields have been disappointing. The average yield achieved by wheat farmers was 1.36 t/ha, only 6% higher than the average of 1.28 t/ha for the crop 20 years ago (Hassan and Faki, 1993).

The most important factors affecting wheat production in the Gezira are seed-bed preparation and crop establishment practices (Babiker *et al*, 1991; Ageeb, 1992; Hassan and Faki, 1993): these factors have been highlighted as areas requiring further research.

2.10 Objectives of the Project

1. To investigate the effects of the Reduced Tillage System proposed as a basis for this Study, and five sowing methods with two seed rates on wheat establishment, growth development and grain yield, under the Gezira conditions.

2. To study the effects of different sowing systems on different types of seed-bed (flat-ridges-beds) on land which has slight undulations with subsequent problems of germination failure due to insufficient soil moisture or washing seeds from the surface by the applied flooding irrigation water.

3. To investigate the effects of five sowing methods with the recommended wheat variety Debeira at lower and higher seed rate levels than used by farmers as standard practice on The Recommended Tillage System (Agricultural Research Corporation) and their effect on wheat establishment, crop performance and grain yield under heavy, cracky clay soil conditions.

4. To determine the optimum depth of disc harrowing on flat vertisol land for wheat emergence, development and yield response under hot irrigated environments.

5. To determine the required power, fuel consumption, field capacity, soil disturbance and operating cost of machines for each operation in seed-bed preparation. Also the assessment of the effects of different harrowing speeds on different aggregate sizes distributed on the soil surface at the first disc harrowing.

3.0 MATERIALS AND METHODS

3.1 Study Area and Layout of the Land

The site of the experiment was located on the Gezira Research Station Farm at Wad Medani, Sudan during the 1993/1994 season. Experiments were carried out on a field of approximately 10 feddans area. (Latitude 14° 26' N, Longitude 33° 30' E)

The soil characteristics on the site were typical of the vertisols of the central clay plain of Sudan, classified as Suleimi Series (fine, montmorillonitic, isohyperthermic Entric Chromusterts) (SSAS, 1983). The Gezira soil was uniform in textural composition throughout, heavy (50-59% clay), strongly alkaline (pH 7.5-9.00), low in nitrogen content (0.02%) and low in organic matter. There is strong swelling and cracking behaviour of the soil during wetting and drying respectively. The clay fraction is dominated by montmorillonitic clay minerals (Green and Snow, 1939; Fink, 1961; Willcocks and Browning, 1986).

Mechanical and chemical analysis of the experimental soils are shown in the Appendix (**Tables 2** and **3**).

3.2 EXPERIMENT 1

The first field experiment was laid out in a randomized complete block design field (Hawasha) Number 241 with five depths of harrowing treatments. Each treatment was replicated five times. The experimental area was 5 feddan (2.1 hectare) divided into 25 plots. The layout of the field is shown in **Figure 3.1.**

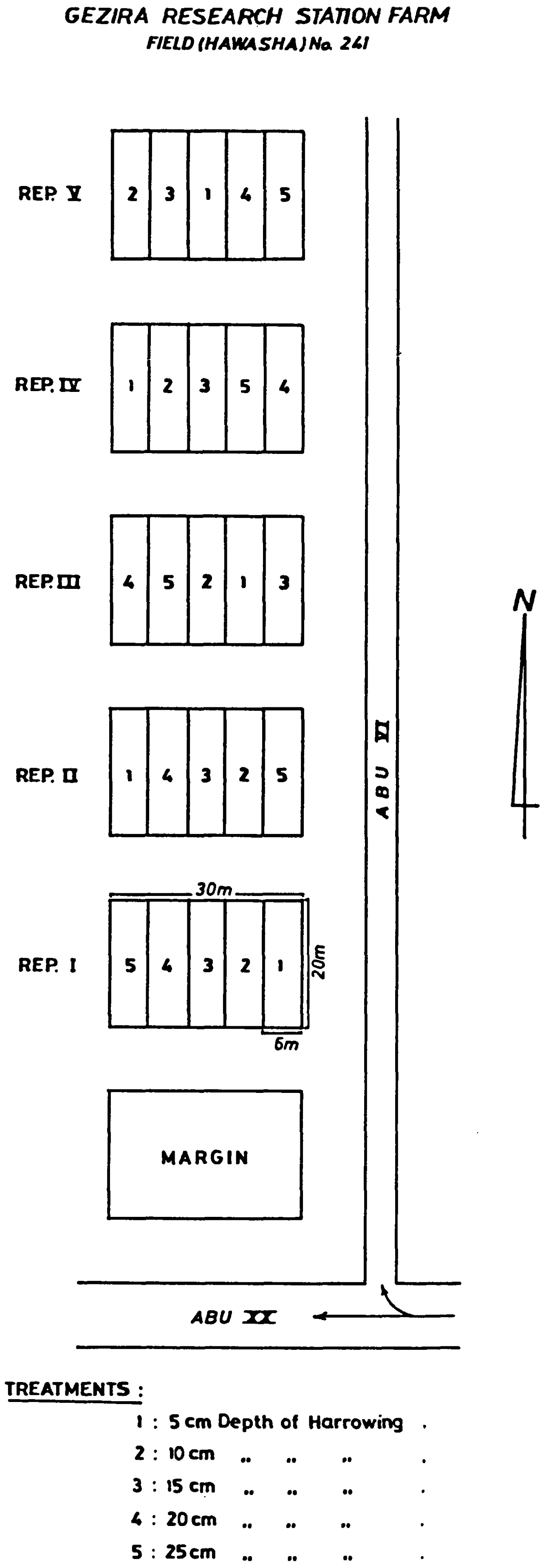


Figure 3.1 The layout of Experiment 1

3.2.1 Seed-bed Preparation and Tillage Equipment

Land preparation started in mid-November 1993 and included the following operations:

1) Disc harrowing at depths of 5 and 10cm were carried out using a Tandem trailed Nardi Disc Harrow (Italy) with the effective width of 1.8m, provided with depth wheels adjustable to allow the discs to penetrate to different required depths, pulled by a Case International 685 tractor (75hp).

2) Disc harrowing at depths of 15, 20 and 25cm was carried out by a Caterpillar D5B Tractor attached to a trailed two-gang offset disc harrow (Rome AH200 - USA) with the effective width of 3.3m, provided with depth wheels adjustable to allow the discs to penetrate to different required depths. A "Camara" levelling device was used to level and consolidate the soil surface (**Plate 3.1**).

Fertilizers applied by drilling (Öztarim - Turkey) at a depth of 5cm below the soil surface at recommended doses of 80kg/f Urea and 50kg/f Superphosphate.

Dressed seed wheat, variety Debeira, was tested for germination in the laboratory. Results showed 100% germination. The seed was drilled on 30th November 1993 at the rate of 50kg/f using a John Deere 8200 Seed Drill. Row widths were set at 20cm. Drilling was on flat land. Surface trash was collected manually and burned. Boundaries of the experimental area were lifted manually using a type of hoe (**Plate 3.2**), to control water over the field (**Plates 3.3 and 3.4**). A tractor-mounted ditcher was used to prepare the sub-main water channel (Abu VI).

Plate 3.1 A 'Camara' levelling device in operation.

Plate 3.2 Site boundaries (to control water supply) being constructed by hand labour using hoes.

Plate 3.3 Shows the first irrigation process

Plate 3.4 Shows the third irrigation applied over the field.

The first irrigation was on the same day as sowing and a total of eight irrigations were applied at 10-14 day intervals depending on the weather conditions. Anti-aphid insecticide Primor - DG (0.1kg/f) was sprayed once on 10th February 1994 using a motorized sprayer.

Harvesting took place in the first week of April 1994. Samples were harvested manually, labelled and weighed in the field.

A Hege - 125C (Germany) Experimental Combine Harvester was used for threshing, separating and cleaning the collected samples, being fed manually.

3.3 EXPERIMENT 2

The second experiment was conducted at the Gezira Research Station Farm Field Number 242. The design of the experiment was Split Block with Recommended and Reduced Tillage Systems on the main plots. The Gezira Research Station recommended system was used on the control plots. Sub-plots with two seed rates, 60kg/f (A) and 40kg/f (B) and five sowing methods were arranged factorially to make twenty treatments, distributed randomly. Sowing methods included:

1) A conventional drill placing seeds in 20cm wide rows at a depth of 5cm on flat land. Covering was by using 58cm diameter rubber wheels attached to the drill. The seed metering mechanism was the external fluted roller type.

2) Wide Level Disc type drill, placing seeds in 20cm wide rows at a depth of 7cm on flat land. Covering was by using 40cm diameter discs attached to the drill. The metering mechanism was of the external fluted roller type. Shown in **Plate 3.5.**

3) Wide level disc type drill on 40cm ridges.

4) Wide level disc type drill on 60cm ridges.

5) Wide level disc type drill on 120cm ridges.

The experimental area was 5 feddans (2.1 hectares) divided into 8 main plots, with four replications; the layout of the field is shown in **Figure 3.2a.**

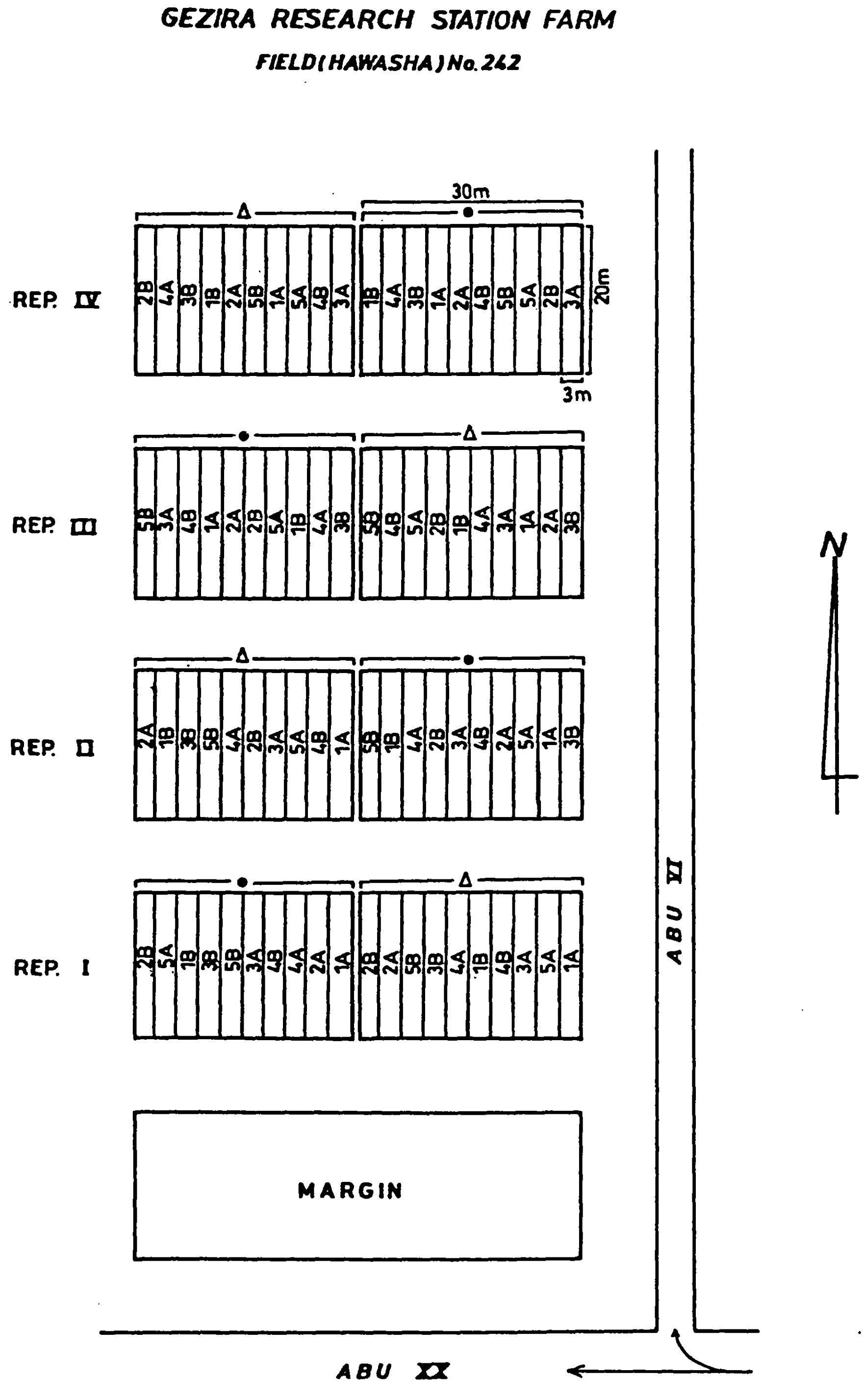
3.3.1 Seed-bed Preparation and Tillage Equipment

3.3.1.1 Recommended Tillage System under Semi-dry Conditions

The recommended land preparation for wheat production in the irrigated heavy clays of the Gezira area is two disc harrowings. However, the recommendation does not specify the depth of harrowing. The time of first disc harrowing is during the rainy season, which was done in September 1993 at 10cm depth. The second one was just before seeding which was carried out in mid-November 1993 at the same depth, using a tandem trailed disc harrow pulled by a Case International 685 Tractor (75hp), followed by a "Camara" levelling device.

Fertilizers were applied at the rates of 80kg/f Urea and 40kg/f Superphosphate by means of a Vicon (Holland) distributor.

Plate 3.5 Wide level disc type drill (WLD)



TREATMENTS :

Main Plot
- • Recommended tillage .
- Δ Reduced tillage .

Sub Plot:

A = Seed rate 60 kg/F
B = Seed rate 40 kg/F
1 = Seed drill + 20 cm Flat .
2 = WLD + Flat
3 = WLD + Ridges 40 cm.
4 = WLD + Ridges 60 cm .
5 = WLD + Beds 120 cm .

Figure 3.2a The layout of Experiment 2

Wheat, cultivar Debeira, was sown on 27th November 1993 at two different seed rates using a 3.0m John Deere 8200 seed drill and a matching wide level disc type drill. Sowing was followed immediately by using a ridger to form furrows to channel irrigation water along the length of the plot according to the layout of the experiment.

A total of eight irrigations were applied at 10-14 day intervals depending on the weather conditions. Anti-aphid insecticide, Primor - DG (0.1kg/f) was sprayed once on 10th February 1994 using a motorized sprayer.

Harvesting was in the first week of April 1994.

Samples were harvested manually, labelled and weighed in the field. A Hege - 125C (Germany) Experimental Combine Harvester was used for threshing, separating and cleaning the collected samples, being fed manually.

3.3.1.2 Reduced Tillage System

Various tillage systems are being adopted in wheat cultivation areas which are dependent on the availability and cost of equipment.

The reduced tillage system which is proposed as the basis for this study of wheat production under semi-arid conditions in the Gezira area by using a ridger, is ridging during the rainy season, followed by ridge splitting, manual clearing of surface trash and drilling with the wide level disc type drill.

Fertilizers were spread at the rates of 80kg/f Urea and 40kg/f Superphosphate using a Vicon distributor after drilling. This is followed by the Camara and then the ridger to form furrows to channel irrigation water along the length of the plot according to the layout of the experiment.

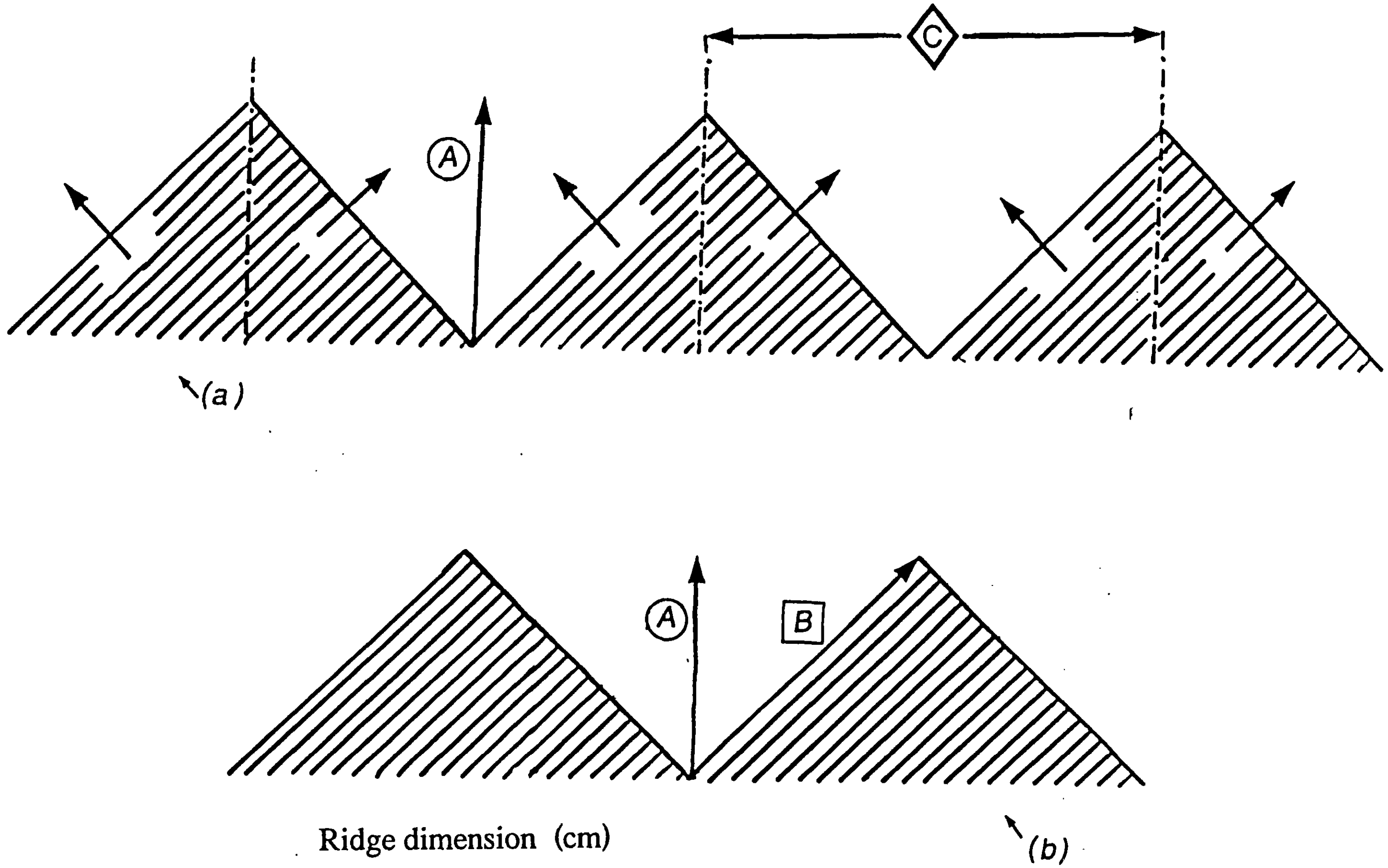
The use of a ridger is proposed, because it is readily available, as it is already used for vegetable and cotton production, and is easily made. The dimensions of the ridges to be used are shown in **Figure 3.2b.**

Ridging was performed in September 1993 using a 3-bodied, mounted ridger with 80cm distance between the tops of ridges, pulled by a Case International 685 tractor (75hp), shown in **Plate 3.6.**

Ridges were split using a ridger pulled by the same tractor, just before seeding in mid-November 1993. Shown in **Plate 3.7.**

Wheat, Cultivar Debeira, was sown on 27th November 1993 at two different seed rates using a 3.0m John Deere 8200 seed drill and matching Nardi wide level disc type drill.

The plots were irrigated on the day of sowing. Irrigation, chemical applications and harvesting operations were carried out as for and at the same time as those on the Recommended Tillage System.



Ridge dimension (cm)

A Ridge height 10-15cm

B Shoulder length 24, 32, 60cm

C Distance between centre line of ridges 40, 60, 120cm

Figure 3.2b A diagram of ridge dimensions, ridging and ridge splitting of reduced tillage system.
(a) soil position after ridging
(b) soil position after ridge splitting

Plate 3.6 The first ridging operation during the rainy season 1993/94

Plate 3.7 The ridge splitting operation

3.4 Data Collection

The effects of treatments on soil physical properties were assessed by the following:

3.4.1 Soil Parameters

3.4.1.1 Soil Aggregates Distribution

Soil aggregate size distribution on the soil surface studied earlier by Van Bavel (1949); Stirk (1958); Chepil and Bisal (1943) and Schaller and Stockinger (1953) were assessed by using a manual set of soil sieves at sizes of 50, 40, 30, 20, 10 and <10mm. Soil samples were taken at 10cm depth after cultivation, with a steel frame of 30cm x 30cm x 10cm. Weight of different aggregate sizes of each sample taken were weighed separately on a sensitive balance in the field and moisture content of the soil during the different measurements was determined.

On the first experiment (field 241), the first disc harrowing was carried out at different depths (5, 10, 15, 20 and 25cm). Manual sieving was done after the first harrowing and two samples of each plot of the experiment were taken on 24th October 1993 at 5.8% soil moisture content.

Further aggregate sieving for the same experiment was carried out after sowing at soil moisture content 7.3%, and two samples of each plot were taken for weighing different aggregate sizes of each sample taken separately.

For the second experiment (field 242), clod size distribution measurement was carried out after sowing, at 7.0% soil moisture content to measure the effects of recommended and reduced tillage systems with different sowing methods.

Two samples obtained by manual sieving for each plot of the experiment were taken using the same set of soil sieves and techniques as mentioned in Experiment 1.

3.4.1.2 Soil Strength

Soil strength was determined as resistance to penetration: it was measured periodically at 2, 8 and 13 weeks after sowing. For both experiments, the penetrometer used was an Eijkelkamp (The Netherlands). Shown in **Plate 3.8.** The instrument gave readings in kN/cm^2, these figures being converted to MPa by multiplying each reading by 3. Readings were taken after irrigation when the soil was at field capacity (approximate moisture content of 40% wet basis for the Gezira heavy clay soils), and it was used for measuring soil penetration resistance as described by Bradford (1986).

Penetration readings were taken four times per plot to depths of 5, 10, 15, 20, 25, 30, 40 and 50cm. Moisture content was determined after irrigation by sampling and drying in a laboratory oven, samples being taken two to three days after irrigation.

Plate 3.8 EIJKELKAMP Penetrometer

3.4.2 Crop Parameters

The aim of the experiments on the Debeira wheat was to measure growth, development and yield response under hot, irrigated environments and these factors were assessed by the following the Third International Heat Stress Genotype Experiment 1991/92 (IHSGE) which is recommended by the International Maize and Wheat Improvement Centre (CIMMYT, Mexico). Due to the large size of the experiments and to avoid any bias, samples were taken for both experiments, according to the prepared sampling maps during the growing season as follows:

3.4.2.1 Seedling Emergence

This sample was taken two weeks after sowing for each plot of both experiments using a frame of size 50cm x 20cm ($0.1m^2$) to count plants per square metre. This is shown in **Plates 3.9** and **3.10**. Shoot and root measurements were determined for each sample collected. Shoot and roots were oven dried at 70°C for 48 hours then weighed on a sensitive balance to obtain the dry weights.

3.4.2.2 Five Leaves Emergence

The second sample was taken on 12th January 1994, at 4 to 5 leaf stage on main stem, for each plot of both experiments using $0.1m^2$ frame to count plants per square metre after some development of vegetative growth. Shoot and root dry weights were obtained for each sample collected.

Plate 3.9 Shows sample collection according to the sampling maps using 50cm x 20cm frame.

Plate 3.10 Shows seedling emergence (20cm wide rows)

3.4.2.3 Flowering Stage (Anthesis)

The third sample was taken at flowering stage on 9th February 1994 for each plot of both experiments, using the frame of $0.1m^2$ to count plants per square metre. Dry weights for shoots and roots were obtained for each sample collected, using the same technique as for previous samples.

3.4.2.4 Yield and Components

Harvesting was started at the end of March 1994, when the grain moisture content was 6%. On the field, the number of plants and number of heads were counted for each plot by using a wooden frame $1m^2$ in area. Plant height was measured three times for each plot, using a 1.0m rule. Samples for yield were taken from the centre of each plot with a sampling area of $3.6m^2$ (1.2m x 3m), as recommended by the Third International Heat Stress Genotype Experiment 1991/92 (CIMMYT).

Harvesting of samples was carried out manually, samples being tied in bundles, weighed in the field and labelled. One hundred fertile shoots (with heads) were taken from each bundle, labelled and put into separate paper sacks for further calculations in the laboratory. Yield components measured also included biological yield, 1000 grain weight, number of grains per head, grain yield and Harvest Index.

These measurements were carried out for both experiments.

3.4.3 Machine Parameters

Some measurements of machine performance were carried out under the dry vertisol conditions at the Gezira Research Station Farm.

One of the most important tillage implements in the Sudan is the disc harrow which is often used in the preparation of seed-beds. Farmers are interested in good seed-beds, but they do not understand that it is necessary to use a proper speed of harrowing to achieve an optimum seed-bed.

3.4.3.1 The Effect of Different Forward Speeds of the First Harrowing on the Different Aggregate Sizes Distributed on the Soil Surface.

The field tests were carried out on 28th October 1993 with a trailed tandem disc harrow (Nardi - Italy) powered by a Case International - 685 Tractor. Tests were carried out at 10cm harrowing depths using different gears, but with the tractor engine running at a constant rev/min as follows:

Gear Speed	Engine Rev/min
First gear slow	1600
First gear high	1600
Second gear slow	1600
Second gear high	1600
Third gear slow	1600
Third gear high	2165
Fourth gear slow	1600

3.4.3.2 Speed of Operation

Actual operation speeds of harrowing km/h were measured using two range poles to cover the distance of 50 metres between the assumed lines. A stop-watch was used to record the time in seconds of travel of tractor and disc harrow between the two range poles. Each run of different gears was carried out three times for each gear. Speed of operation was calculated by using the formula:

$$S \text{ m/sec} = \frac{D}{T}$$

Where,

S = Speed (m/sec)
D = Distance (m)
T = Time (sec)

and the actual speeds converted to km/h.

3.4.3.3 Wheel Slip

Narayanrao and Verma (1982) method of determining the wheel slip was followed. The method involves making a chalk mark on the drive wheel of the tractor and measuring the distance the tractor travels in 10 revolutions of the wheel with no load (A), and with load (B). The wheel slip was calculated by using the formula:

$$WS(\%) = \frac{A-B}{A} \times 100$$

Where,

WS = Wheel Slip (%)

A = Distance travelled with no load (m)

B = Distance travelled with load (m)

The wheel slip measured when using the disc harrow was 17.5% where soil moisture content was 5.6%.

Different aggregate sizes on the soil surface due to the different operation speeds are shown in **Plate 3.11**. The soil was sieved manually using a set of soil sieves of 50, 40, 30, 20, 10 and <10mm; samples were taken five times from each run at 10cm depth by using a steel frame of 30 x 30 x 10cm with the soil at 5.6% moisture content.

The mean weight of different aggregate sizes of each collected sample were weighed separately on the field by using a sensitive balance and recorded. Shown in **Plate 3.12.**

3.4.3.4 Fuel Consumption

An external fuel tank with reading level was attached to the tractor, connected to the primary filter, the other end from the diesel pump returning to the external tank.

The external tank was filled to its top level before testing the different implements in each test plot of 50m x 25m area. After each operation by different equipment in the test plot, the external fuel tank was refilled to the same fuel level with a 1000 millilitre graduated cylinder, using a spirit level to ensure that the tractor was level. The total quantity of diesel fuel needed to refill the fuel tank to the same mark was recorded and the total time taken for different operations on the test plot was also recorded and the fuel consumption per hectare was calculated. The measurement of fuel consumption is shown in **Plate 3.13.**

Plate 3.11 Land disc harrowed at different forward speeds.

Plate 3.12 Sieving to extract mean weight of aggregate sizes.

Plate 3.13 Fuel consumption measurement by using external tank.

3.4.3.5 Power Requirement (Draught Measurement)

A) Trailed Equipment

A digital hydraulic pull type dynamometer (Piab - Sweden) reading in 100kN was attached first to the trailed offset Rome disc harrow and Caterpillar D5B tractor to measure draught forces required for different harrowing depths of 15, 20 and 25cm.

The dynamometer was also used for the Recommended Tillage System with the trailed Nardi disc harrow, pulled by the Case International 685 tractor to measure power required for harrowing depths of 5cm and 10cm, shown in **Plate 3.14.**

B) Mounted Equipment

The same hydraulic pull type dynamometer used with trailed equipment was attached to the front of the Case International 685 tractor on which the 3-bodied ridger was mounted to carry out The Reduced Tillage System. Another tractor (Case International 685) was used to pull the tractor and ridger with the dynamometer attached to the linking drawbar, the auxiliary tractor pulling the tractor with the mounted ridger with the rear tractor in neutral gear, but with the implement in the operating position (Narayanrao and Verma, 1982).

Plate 3.14 Dynamometer linking tractor and disc harrow.

The draught was recorded for a measured distance of 50m. The time taken to traverse the 50m was also recorded. On the same field, the implement was lifted from the ground and the rear tractor was pulled to record the unloaded draught force. The difference between the two forces showing the draught of the implement. The measurement of the draught is shown in **Plates 3.15 and 3.16.**

3.4.3.6 Field Capacity and Soil Disturbance

The field capacity (rate of work) was determined by tilling an area 50m long and 25m wide for each speed. The time lost at corners was also recorded. The field capacity of the selected implements was calculated in ha/h by using Hunt's formula (1983):

$$C = \frac{S\,W\,E}{10}$$

Where,

C = field capacity (ha/h)
S = speed of operation (km/h)
W = width of implement (m)
E = field efficiency (70%)

The soil volume disturbed in m^3/h was calculated by using the following formula:

$$V = 10000\,CD$$

Where,

V = soil volume disturbed (m^3/h)
C = field capacity (ha/h)
D = depth of cut (m)

3.4.3.7 Operation Cost

The running costs of the tractor and selected implements for both Recommended and Reduced Tillage Systems were calculated in Sudanese Pounds per hectare (LS/ha).

Plate 3.15 Tractor and ridger being pulled through dynamometer link to measure draught force.

Plate 3.16 Tractor and ridger being pulled through dynamometer link to measure unloaded force.

3.5 Weather Data

Daily maximum and minimum temperature (°C) during the growing season of 1993/94 were collected from the Gezira Meteorological Station and compared with the same data for the growing season 1992/93, shown in the Appendix (**Figure 2**).

3.6 Statistical Analysis

Data sets were analysed by appropriate factorial analyses of variance and standard errors of differences were calculated.

4.0 RESULTS AND DISCUSSION

In the Sudan very limited research work has been done to study the effect of land preparation on soil properties and the growth and yield of field crops. This study puts more emphasis on the effect of different tillage systems associated with different sowing methods on certain soil physical properties, wheat performance and yield and required machine parameters to establish the wheat crop under the Gezira conditions.

4.1 Soil Physical Properties

Seed-bed preparation without primary tillage can lead to difficulties of dealing with surface trash: the soil conditions may be suitable for the crop to become established, but the trash may prevent the seeding or planting operation being carried out satisfactorily.

4.1.1 Soil Aggregate Sizes Distribution

A seed-bed is that layer of soil which has been tilled to a condition to promote germination, emergence and growth of seedlings.

Experiment 1 **(Figure 4.1)** shows effect of five depths of disc harrowing on different mean weight of aggregate sizes which were determined after the first harrowing, and that measurements were significantly different at 50mm (P=0.01), 40mm (P=0.05), 30mm (P=0.01) and 20mm(P=0.001) which are shown in **Figures 4.2, 4.3, 4.4 and 4.5.** Disc harrowing at 10cm and 25cm depth gave the highest mean weight of <10mm aggregate size, although the <10mm size was still high at other depths.

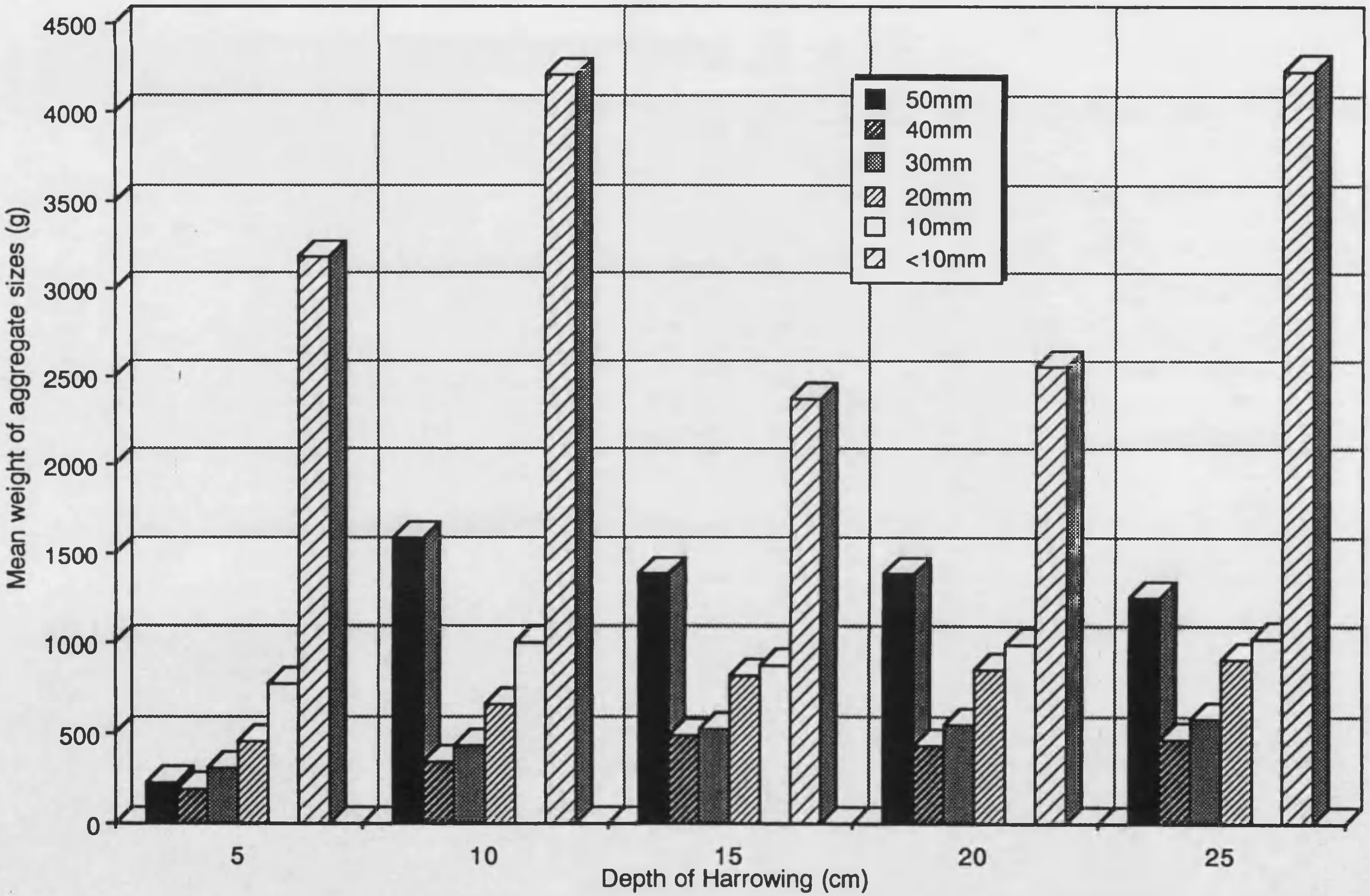


Figure 4.1 Effect of different depth of disc harrowing on different mean weight of aggregate sizes distributed on the soil surface after the first harrowing. (m.c. = 5.8%)

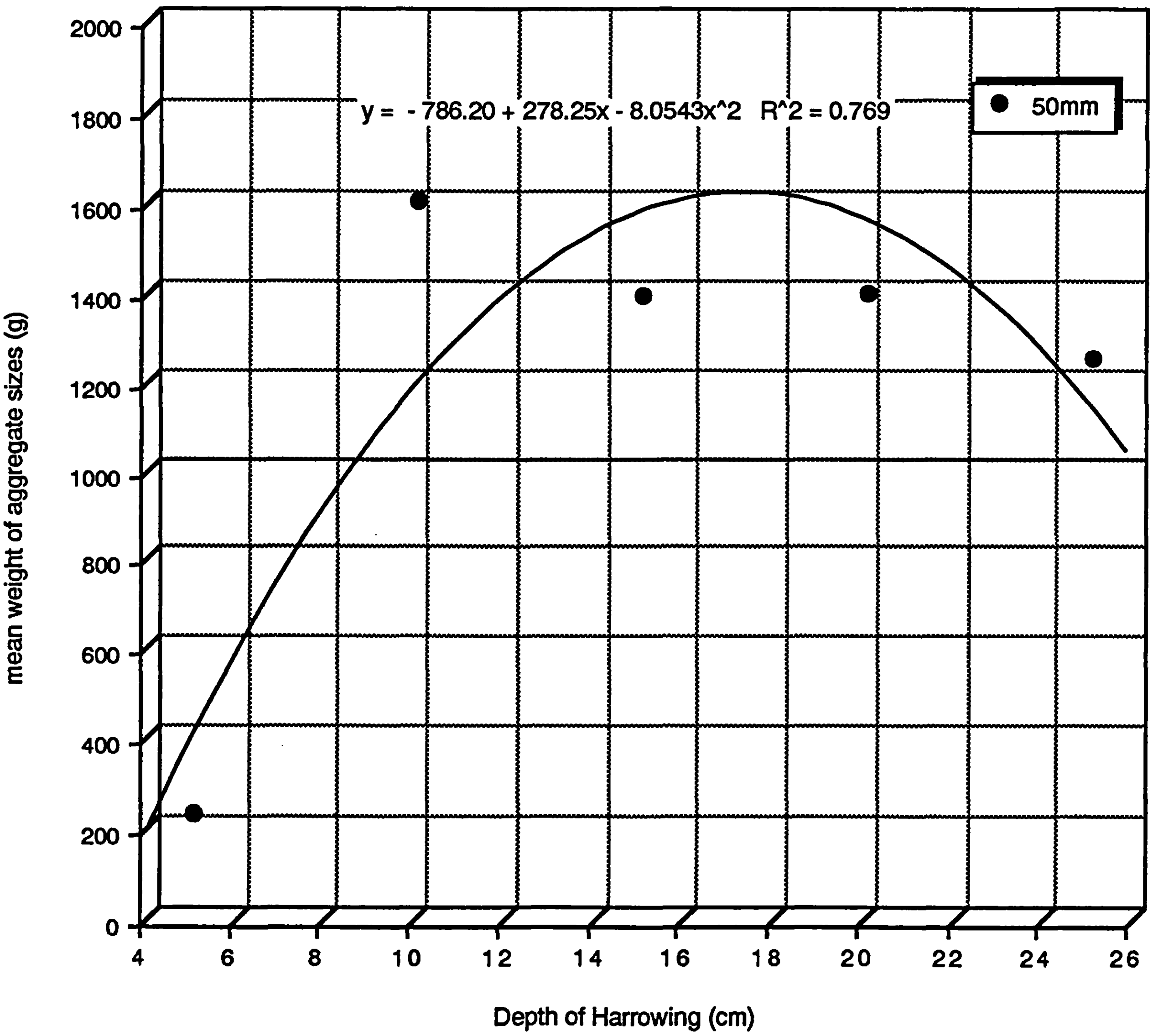


Figure 4.2 Effect of different depths of disc harrowing on 50mm mean weight of aggregate size distributed on the soil surface after the first harrowing. (m.c. = 5.8%)

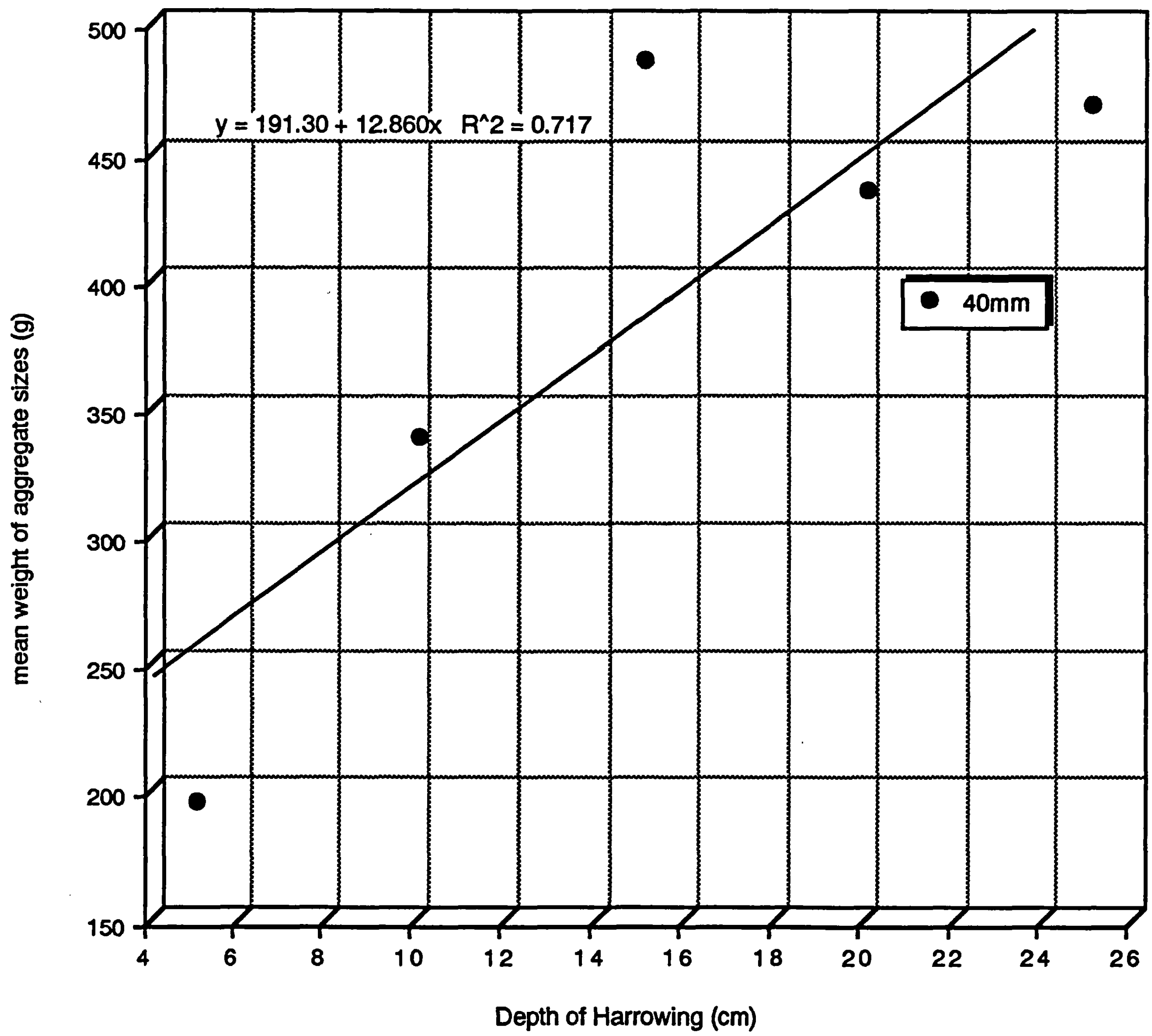


Figure 4.3 Effect of different depths of disc harrowing on 40mm mean weight of aggregate size distributed on the soil surface after the first harrowing. (m.c. = 5.8%)

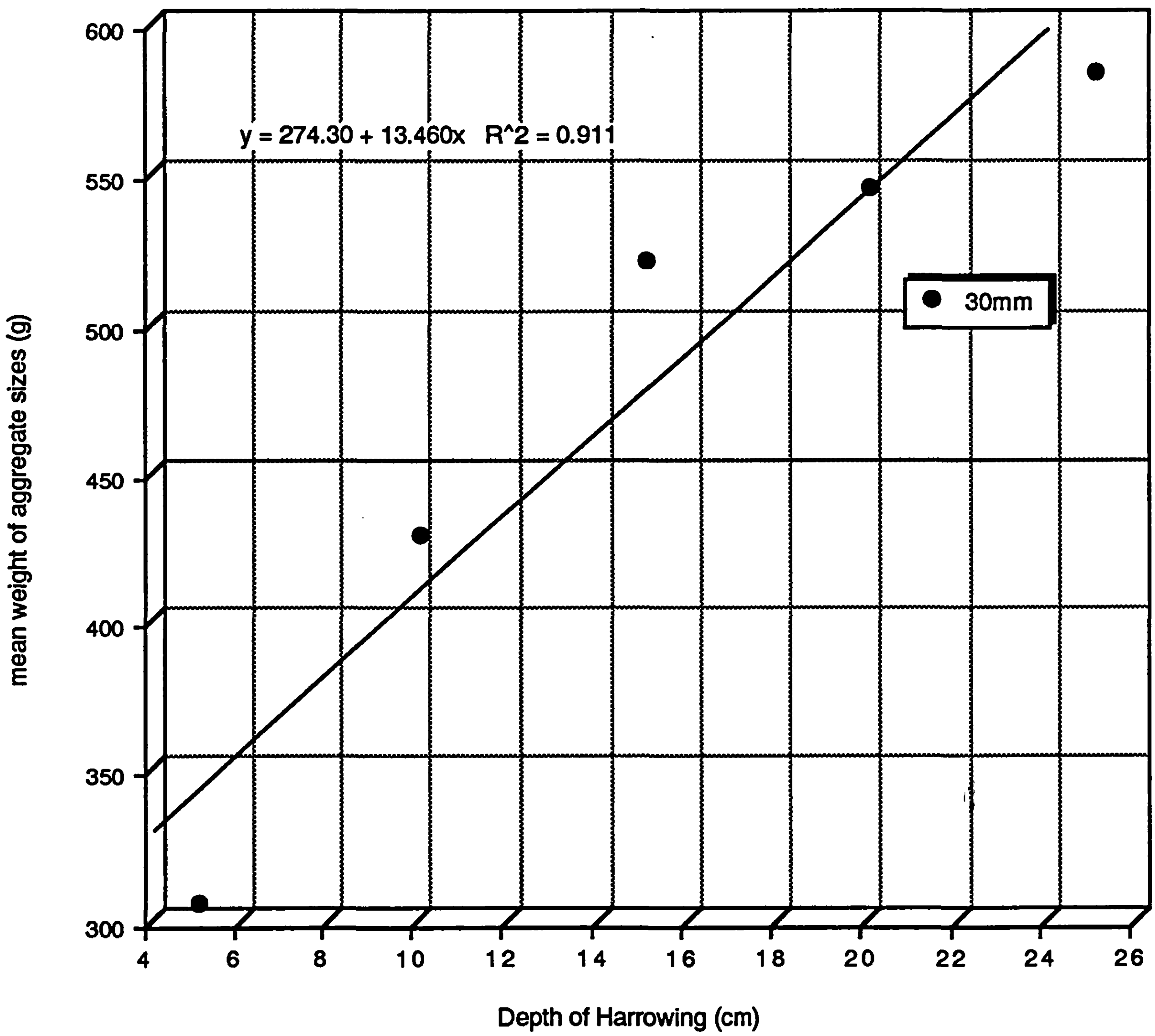


Figure 4.4 Effect of different depths of disc harrowing on 30mm mean weight of aggregate size distributed on the soil surface after the first harrowing. (m.c. = 5.8%)

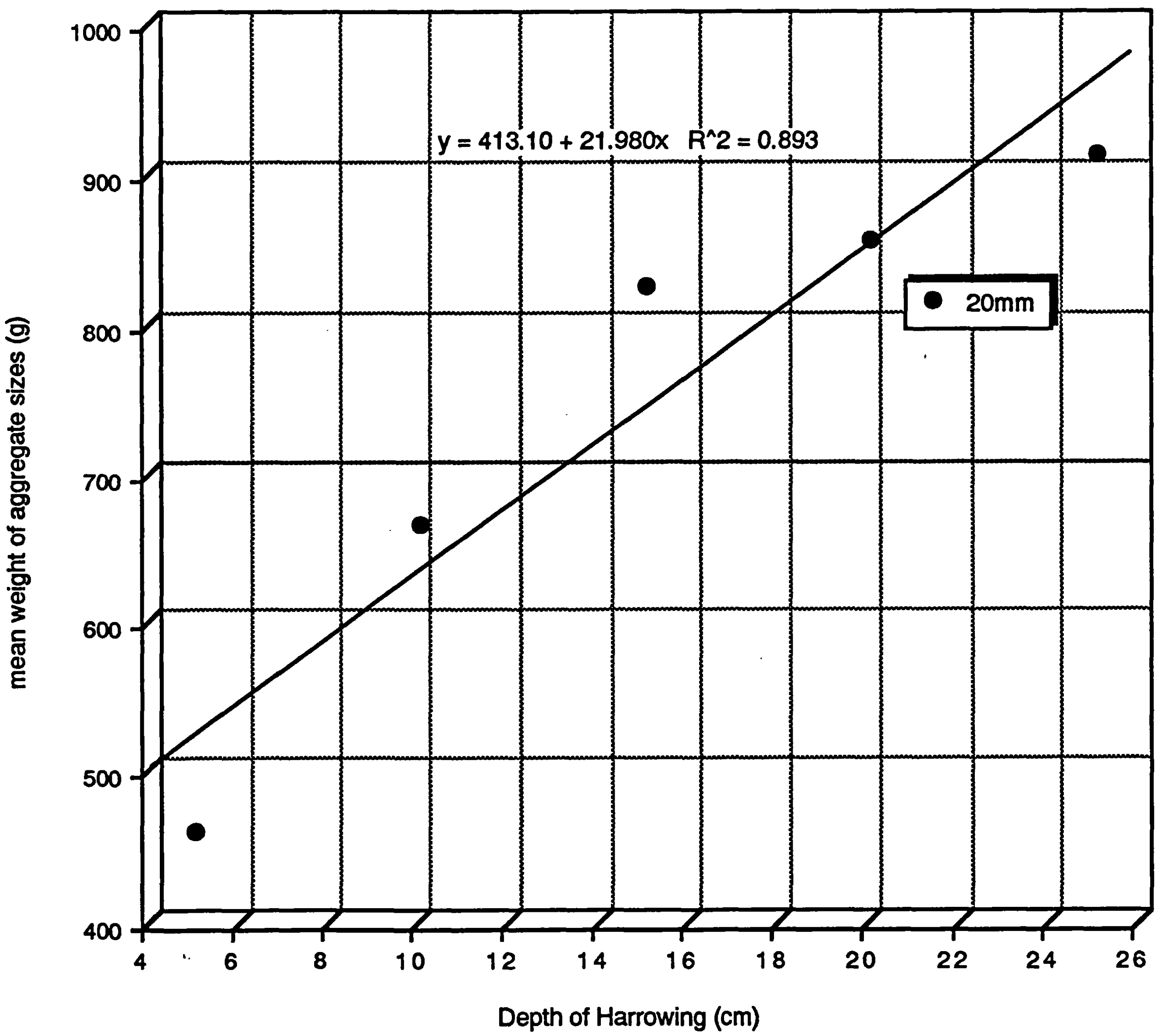


Figure 4.5 Effect of different depths of disc harrowing on 20mm mean weight of aggregate size distributed on the soil surface after the first harrowing. (m.c. = 5.8%)

This was probably due to low moisture content (5.8%) and low trash on the field. Braunack and Dexter, (1989) found the aggregate sizes on the soil surface were influenced under some conditions of soil type, soil moisture content and crop grown. Ojeniyi (1989) from Nigeria carried out experiments to investigate the ploughing requirement for establishment of Cowpea. He found that at reasonable soil moisture content, two passes of a disc plough produced a significantly higher establishment rate, growth and number of leaves.

Figure 4.6 shows the same effect of the five depths of disc harrowing on aggregate sizes after sowing. The results indicated that treatments were significantly different at 20mm (P=0.05) and 10mm (P=0.05 mean weight of aggregate sizes which are shown in **Figures 4.7** and **4.8.**

The results obtained showed that <10mm the mean weight of aggregate size increased markedly in all five depths followed by other aggregate sizes of 10, 20, 30, 40 and 50 mm respectively **(Figure 4.6)**. This probably was due to the further work done by the Camara and the seed drill with some help from rain falling during these operations which raised the surface soil moisture content to 7.3%.

The results agreed with the fact that the amount of soil loosening done under arid and semi-arid conditions is dependent on the variations in combination of implements used (Mohamed Ali, 1991).

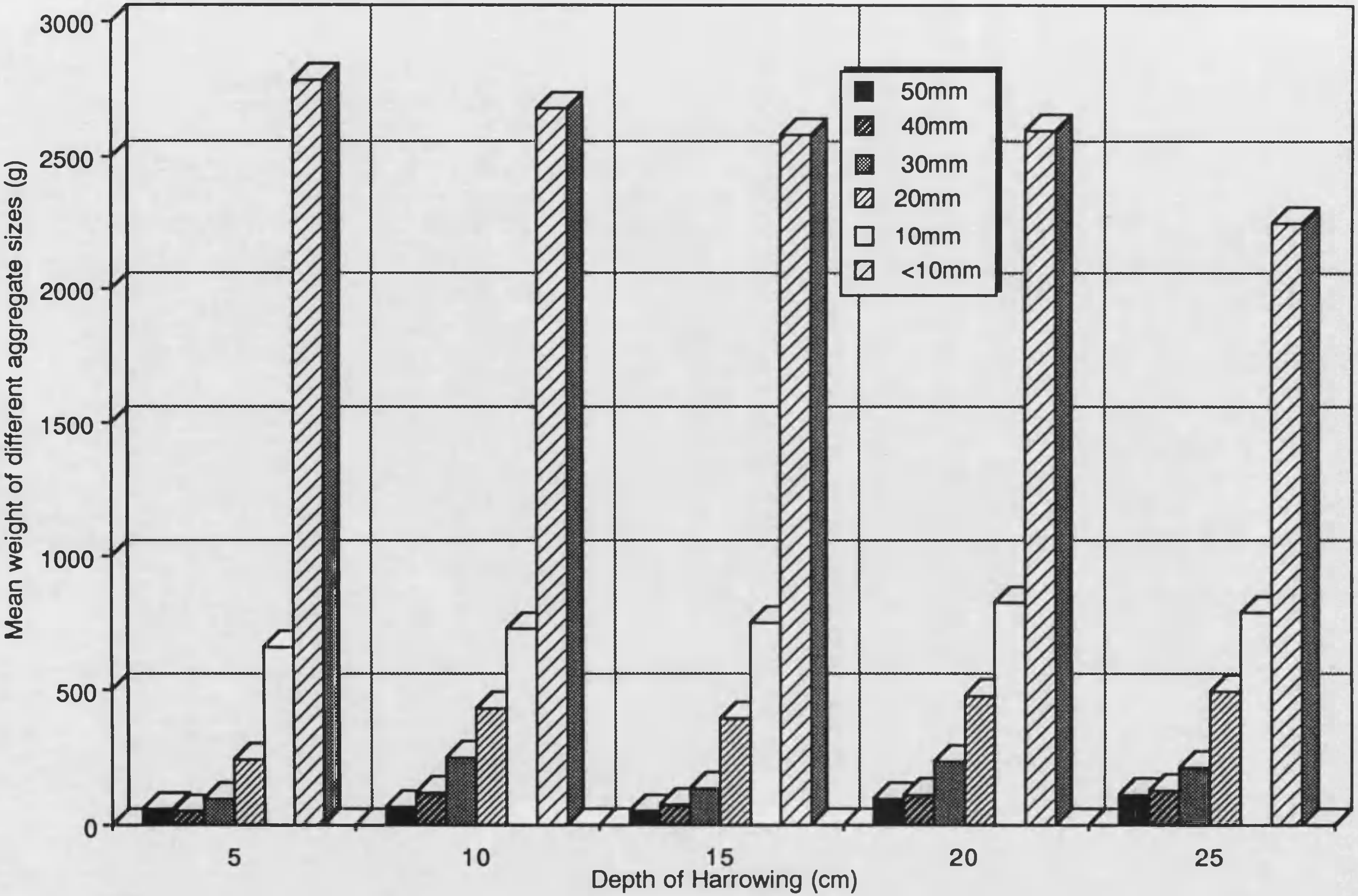


Figure 4.6 Effect of different depth of disc harrowing on different mean weight of aggregate sizes distributed on the soil surface after sowing. (m.c. = 7.3%)

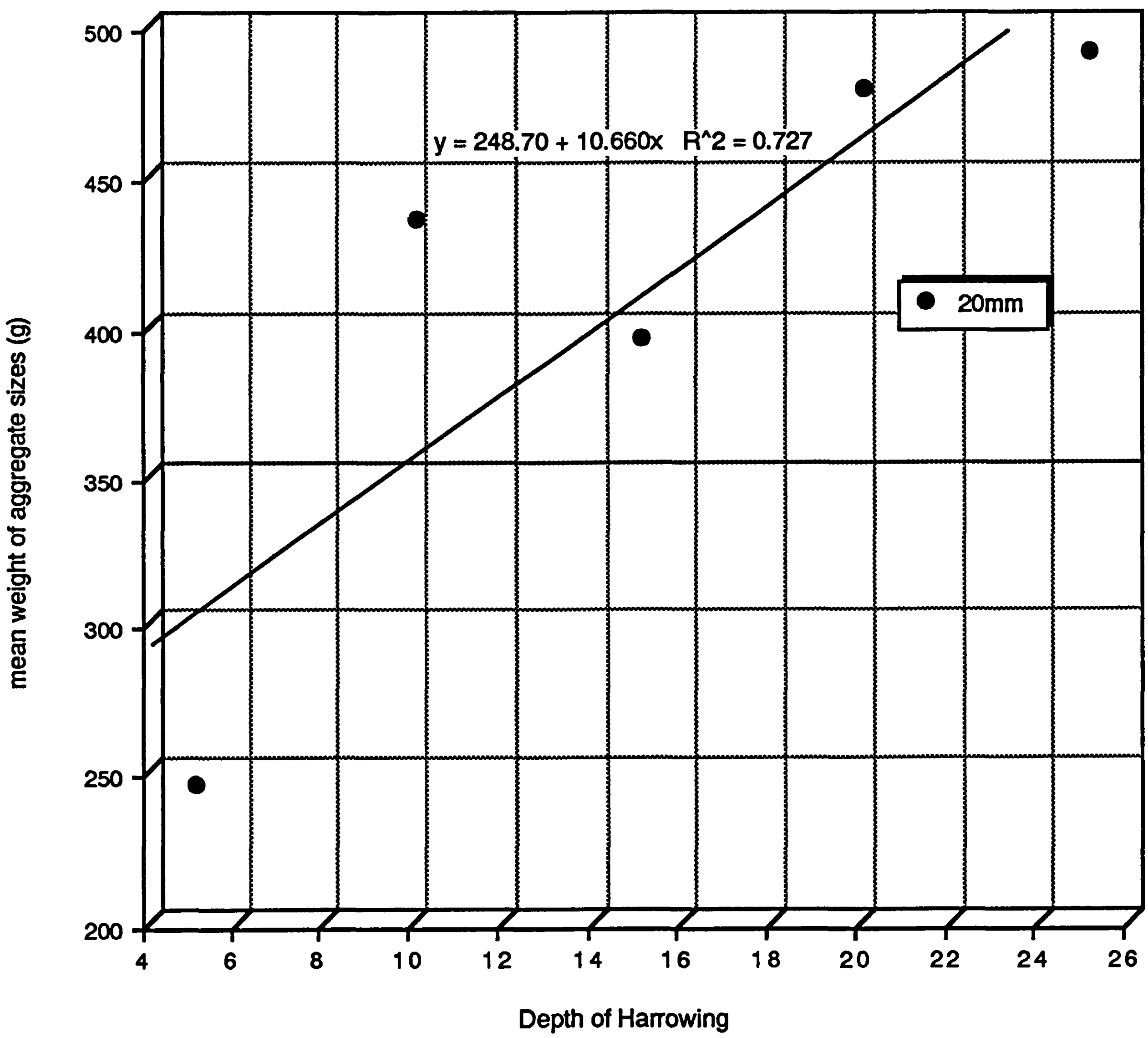


Figure 4.7 Effect of different depths of disc harrowing on 20mm mean weight of aggregate size distributed on the soil surface after sowing. (m.c. = 7.3%)

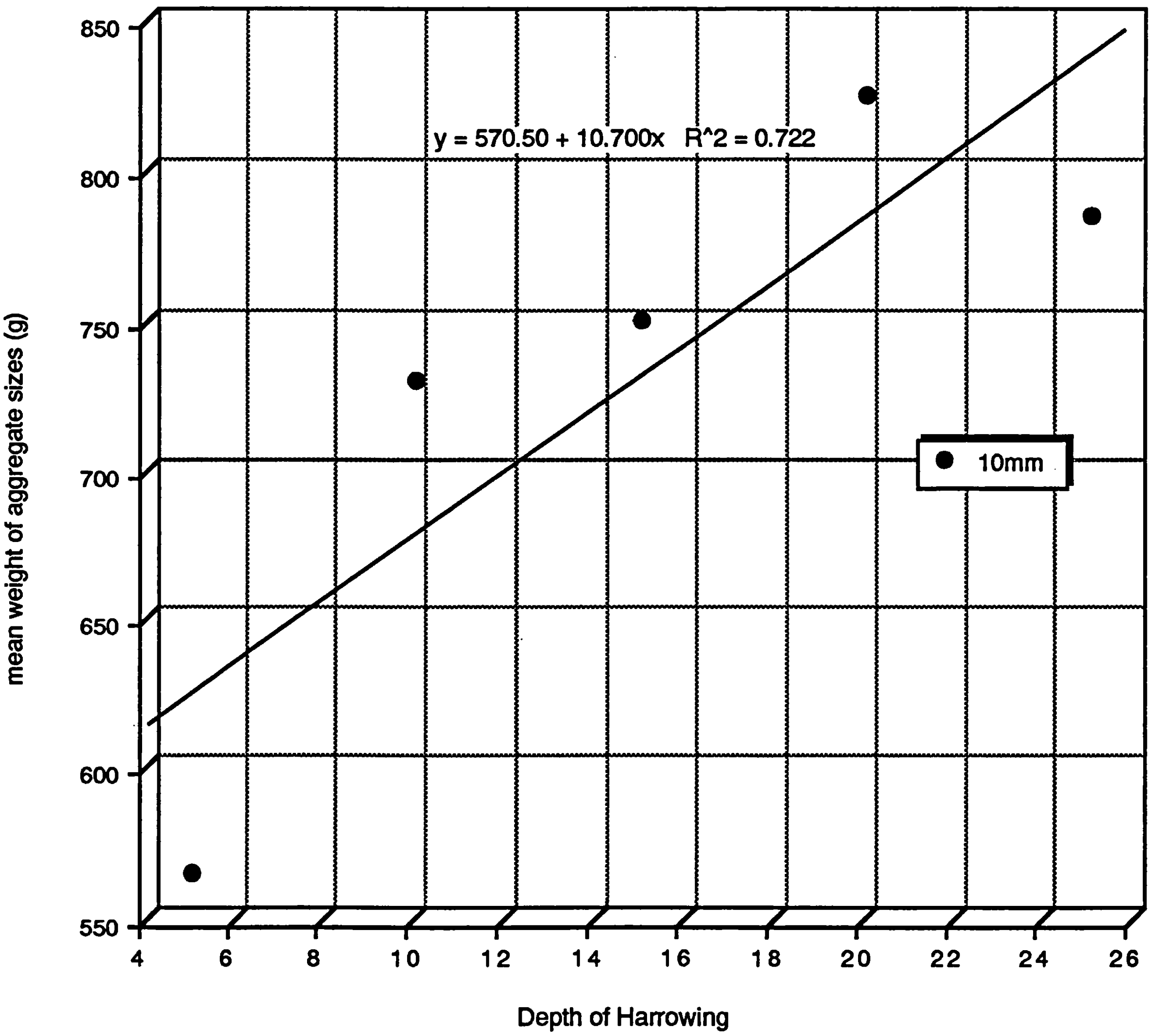


Figure 4.8 Effect of different depths of disc harrowing on 10mm mean weight of aggregate size distributed on the soil surface after sowing. (m.c. = 7.3%)

Experiment 2 (**Figure 4.9**) shows the effect of the Recommended Tillage System associated with five sowing methods and two seed rates on the mean weight of aggregate sizes on the surface after sowing., Its shows that sowing with a seed drill in rows 20cm apart at a depth of 5cm on flat land with 40kg/f seed rate gave the highest mean weight of <10mm aggregate size, whilst the lowest level obtained with the same aggregate size was with a Wide Level Disc type drill, placing seeds in rows 20cm apart at a depth of 7cm on flat land and 60kg/f seed rate.

The other mean weight of different aggregate sizes (50, 40, 30, 20 and 10mm) with different sowing methods and seed rates were decreased markedly. Tillage Systems with different seed rates in the mean weight of <10mm aggregate size were significantly different as shown in **Table 4.1.**

The result showed that the second disc harrowing after the rainy season broke down the large clods on the soil surface (10cm depth).

Further operations done for levelling and seeding caused further break down of clods.

Results for the Reduced Tillage System (**Figure 4.10**) showed that the Wide Level Disc on 60cm ridges at 60 kg/f seed rate gave the highest mean weight of <10mm aggregate size on the surface, however, the lowest level of <10mm aggregate size mean weight with same level of seed rate was shown by the Wide Level Disc on 120cm beds. Also the sowing methods were significantly different with mean weight of 30mm aggregate size for both tillage systems shown in **Tables 4.2 and 4.3.**

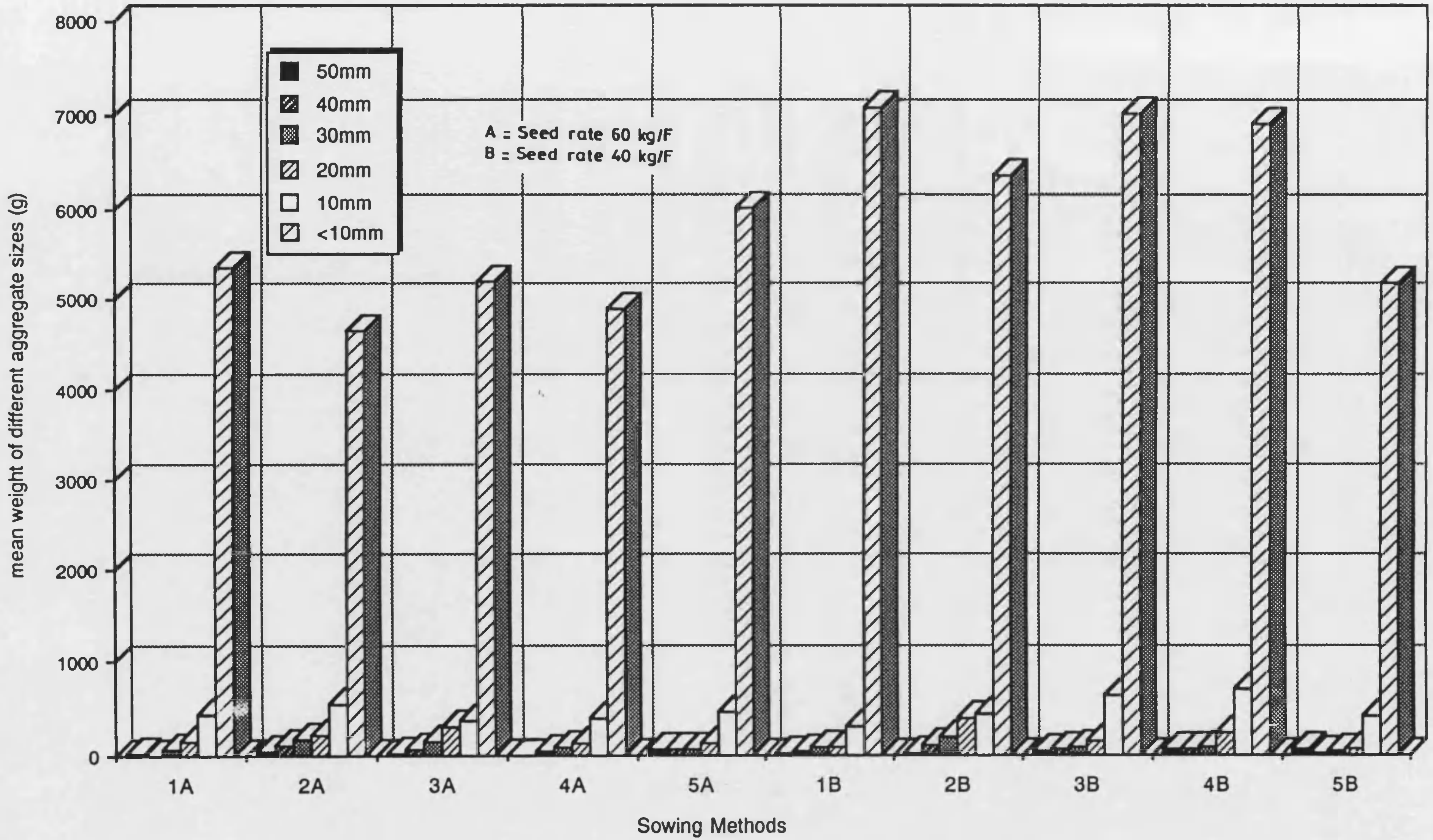


Figure 4.9 The effect of recommended tillage system with different sowing methods on mean weight of aggregate sizes distributed on the soil surface after sowing. (m.c. = 7.0%)

Table 4.1 The effect of different tillage systems with two seed rate levels on the mean weight of <10 mm aggregate size distributed on the soil surface after sowing (m.c. = 7.0%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	5224.0	6513.0
Reduced	6048.0	5868.0

S.e.d.(a) = 447.0
S.e.d.(b) = 425.1
a: For comparing means with different tillage systems
b: For comparing means with the same tillage system
Interaction is significant at p=0.05

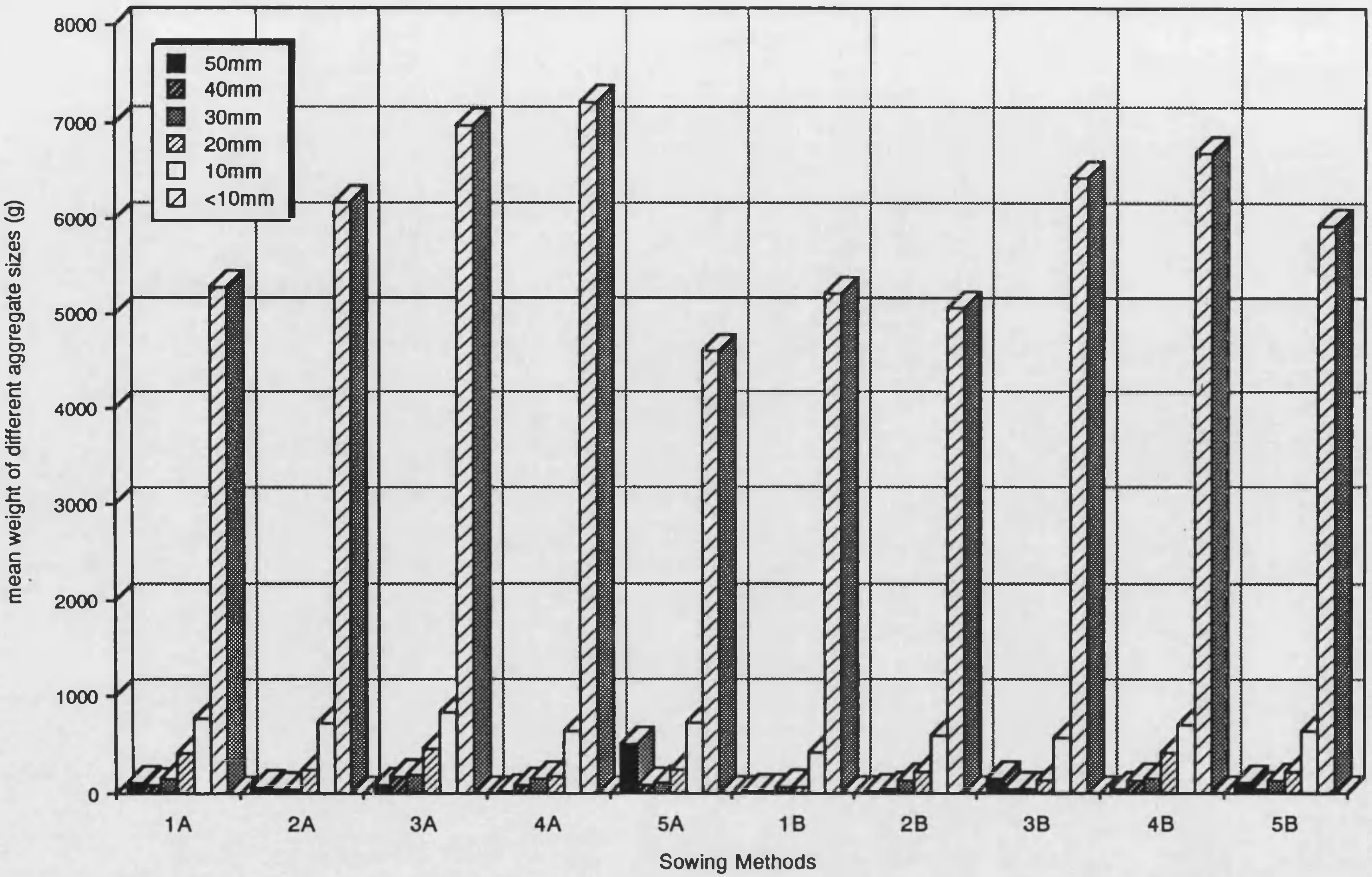


Figure 4.10 The effect of reduced tillage system with different sowing methods on mean weight of aggregate sizes distributed on the soil surface after sowing. (m.c. = 7.0%)

Table 4.2 The effect of different sowing methods and two seed rate levels on the mean weight of 20 mm aggregate size distributed on the soil surface after sowing (m.c. = 7.0%)

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	282.0	81.0
2	224.0	303.0
3	375.0	144.0
4	153.0	325.0
5	181.0	142.0

S.e.d. = 53.4
Significant at P = 0.001.

Table 4.3 The effect of different tillage systems with sowing methods on the mean weight of 30 mm aggregate size distributed on the soil surface after sowing (m.c. = 7.0%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	75.6	105.0
2	181.3	94.4
3	115.6	113.7
4	87.5	143.8
5	46.2	15.6

S.e.d.(a) = 30.95
S.e.d.(b) = 27.42
a: For comparing means with different tillage systems
b: For comparing means with the same tillage system
Interaction is significant at p=0.001

The results obtained showed that on the Recommended Tillage Systems the second disc harrowing after the rainy season (at 10cm depth) was breaking down most clods on the surface, also further operations done for levelling and seeding were causing further break down. In the Reduced Tillage System the operations of ridging and ridge splitting caused complete inversion and break down of the soil especially with sowing on wide ridges of 60cm between centres and in beds 120cm wide.

In fact the soils of the experimental area at the Gezira are vertisols, which are dark brown in colour, with a soft surface mulch resulting from the fracturing of the upper soil layers. Due to their high montmorillonitic clay content (55-60%), vertisols have special problems due to large volume changes (Swelling and Shrinking properties) occurring upon wetting and drying (Willcocks and Browning, 1986). It seems that weather to some extent could help in aggregate size reduction, mainly after the rainy season and during high ambient temperatures as found under Arid and Semi-arid conditions.

Another problem with vertisols is their great stickiness and plasticity (Dexter and Watts, 1992) which can cause deep cracks when relatively dry in most seasons, even a short time after irrigation. These results agreed with the principle that reduction of aggregate sizes depends on soil moisture content and the amount of specific energy required to break clods with powered implements (Cope and Patterson, 1990).

4.1.2 Soil Penetration Resistance

Soil penetrometer readings provide some measure of the energy that must be exerted by the young seedling to emerge from the soil and the root to penetrate into the soil. The readings also indicate the soil resistance to be overcome in search of nutrients and water.

Experiment 1 the effect of different depths of harrowing on soil penetration resistance values (MPa) are shown in **Figure 4.11, 4.12 and 4.13.** **Figure 4.11** shows soil penetration resistance with depths of 5, 10, 15, 20, 25, 30, 40 and 50 cm two weeks after sowing (after the second watering). There were significant differences in penetration resistance between different harrowing depth treatments at different penetration depths. At the upper depths 10cm and 15cm (P = 0.01), while at 20, 25, and 50cm (P = 0.01) and at 30cm and 40cm depths, soil penetration resistance was significantly lower (P = 0.05). This may be attributed to the soil disturbance which was enhanced by the different depths of disc harrowing applied on cracked land.

Figure 4.12 shows soil penetration resistance at the same depths as before, at 8 weeks after sowing. There were significant differences in penetration resistance between treatments at three penetration depths. At the upper depths 10cm and 15cm (P = 0.01), while at 50cm (P = 0.05).

At the end of the growing season, **Figure 4.13** shows soil penetration resistance at the same depths as before at 13 weeks after sowing. There were significant differences in penetration resistance between treatments at four penetration depths including the soil surface.

At the upper depth of 5, 10 and 15cm, penetration resistance was significantly lower (P = 0.05), while at 20cm depth (P = 0.001).

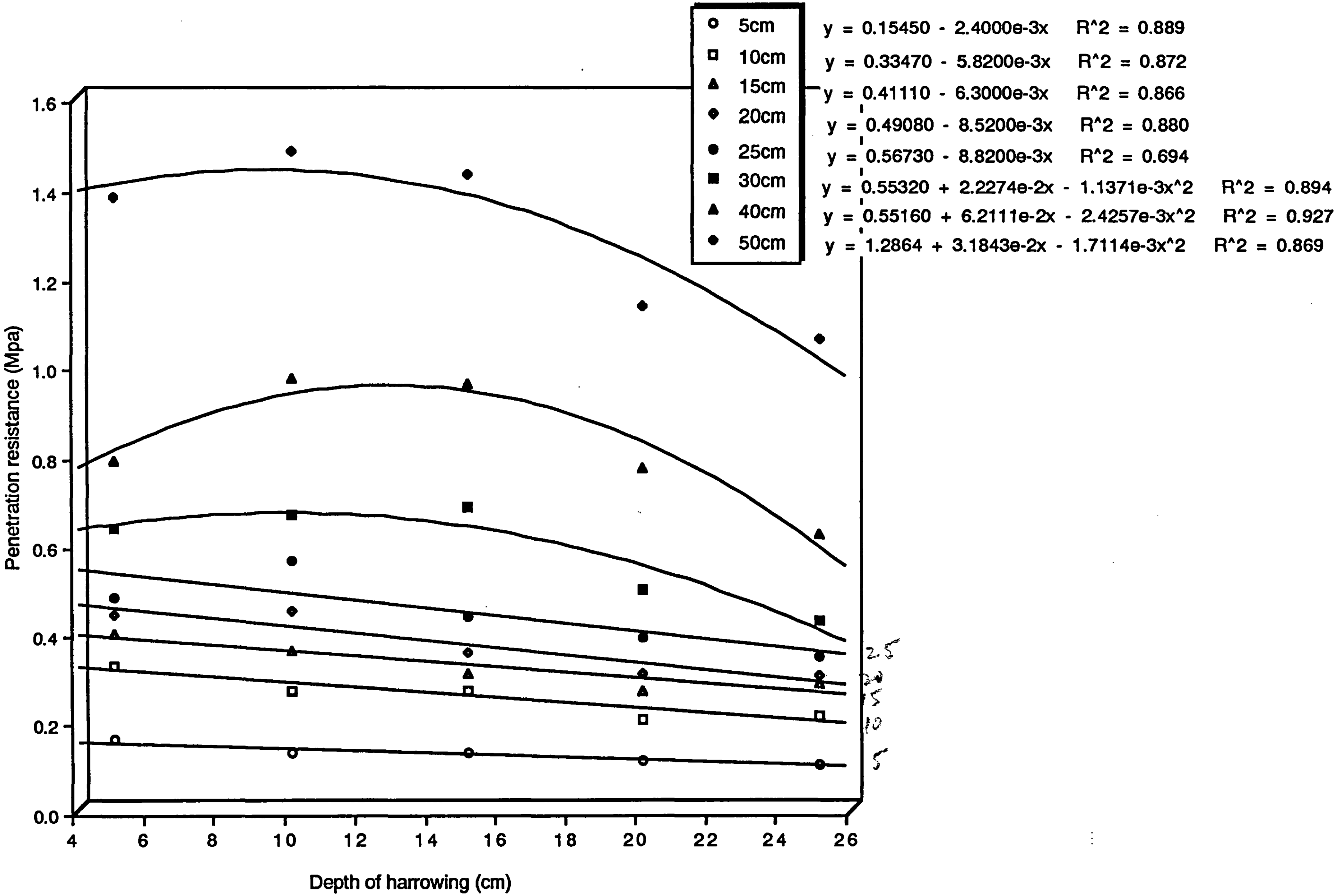


Figure 4.11 Effect of penetration resistance (MPa) of the different depths of harrowing after the second irrigation. (m.c. = 39.2%)

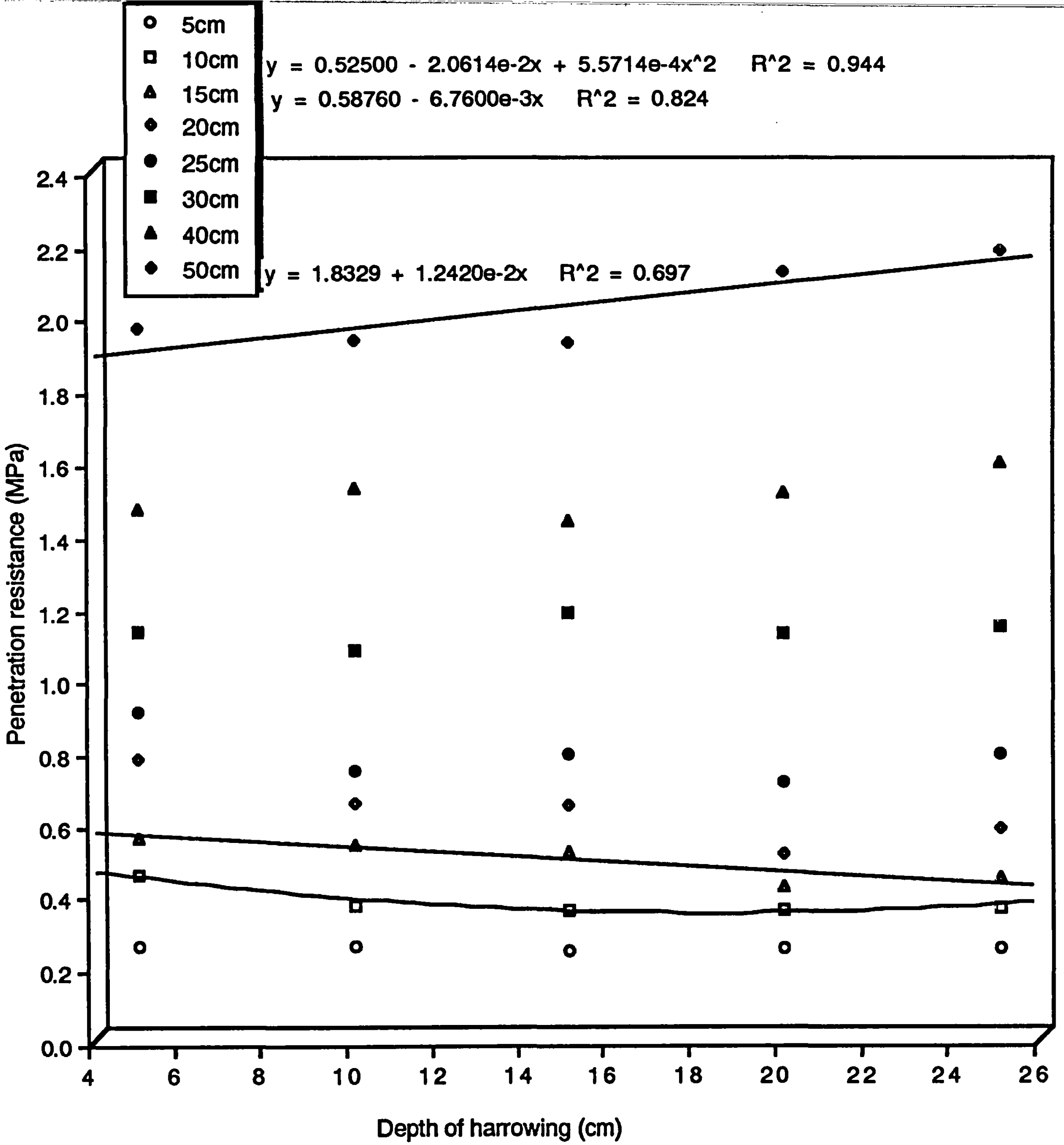


Figure 4.12 Effect of penetration resistance (MPa) of the different depths of harrowing at 8 weeks after sowing. (m.c. = 41.0%)

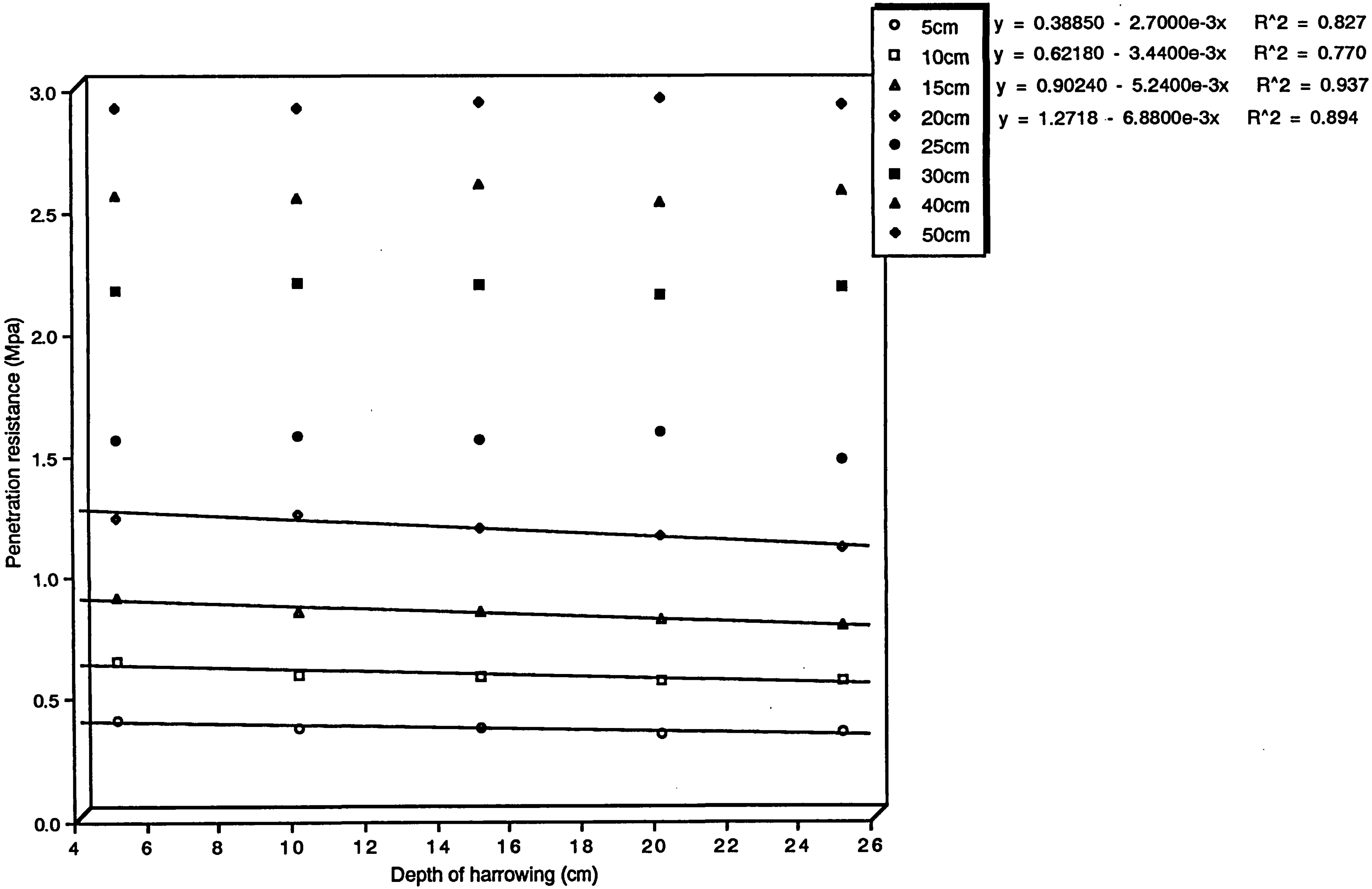


Figure 4.13 Effect of penetration resistance (MPa) of the different depths of harrowing at 13 weeks after sowing (m.c. = 39.4%)

It seems that deep cracks with large fissures in the disturbed treatment plots were not affected by water application at the soil surface (5cm depth) at the beginning of the growing season (2 and 8 weeks after sowing).

These results are in agreement with that of Mughal, (1973) from Pakistan, working on black cotton soils. He found significant differences in the penetration resistance values between different depths of cultivation practices, however, the highest values were observed at 25-50cm depth in tractor drawn tined cultivator plots.

Experiment 2 the effect of The Recommended and Reduced Tillage Systems on soil penetration resistance values (MPa) after the second irrigation are shown in **Tables 4.4** and **4.5**. Results obtained showed that soil penetration resistance at 10cm depth, tillage systems and seed rates showed significant differences (**Table 4.6**), also sowing methods and seed rate levels showed significant differences (**Table 4.7**).

With 15cm depth of penetration within tillage practices, there were significant differences between tillage systems and seed rate levels (**Table 4.8**), also between sowing methods and tillage systems (**Table 4.9**).

With 20cm depth of penetration in both tillage treatments, there were significant differences between tillage systems and seed rates (**Table 4.10**); between sowing methods and tillage systems (**Table 4.11**) and between sowing methods with seed rate levels (**Table 4.12**).

With 25cm depth of penetration within tillage practices, there were significant differences between tillage systems and seed rates (**Table 4.13**); between sowing methods and tillage systems (**Table 4.14**) and between sowing methods and seed rates (**Table 4.15**).

With 30cm depth of penetration in different tillage systems, there were significant differences between tillage systems and seed rates (**Table 4.16**) and between sowing methods and seed rates (**Table 4.17**).

With 40cm depth of penetration within tillage treatments, there was significant difference between tillage systems and seed rates (**Table 4.18**).

Table 4.4 Effect of penetration resistance (MPa) of the recommended tillage System and different sowing methods after the second irrigation (M.C.=40.1%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.230	0.360	0.360	0.370	0.420	0.650	0.930	2.000
2A	0.230	0.310	0.360	0.490	0.590	0.750	0.950	1.750
3A	0.230	0.310	0.370	0.370	0.420	0.500	0.730	1.640
4A	0.280	0.380	0.440	0.480	0.560	0.590	0.700	1.450
5A	0.170	0.210	0.290	0.340	0.360	0.400	0.520	0.970
1B	0.340	0.420	0.480	0.550	0.640	0.690	1.030	2.060
2B	0.160	0.230	0.260	0.300	0.420	0.470	0.740	1.150
3B	0.340	0.420	0.480	0.580	0.660	1.060	1.310	2.260
4B	0.380	0.450	0.520	0.650	0.700	0.820	1.050	1.620
5B	0.360	0.510	0.540	0.610	0.710	0.770	0.960	1.260
S.e.d.(a)	0.0835	0.0751	0.0707	0.0681	0.0889	0.1437	0.2403	0.3234
S.e.d.(b)	0.0798	0.0776	0.0734	0.0634	0.0765	0.1278	0.1958	0.3274

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.5 Effect of penetration resistance (MPa) of the reduced tillage system and different sowing methods after the second irrigation (M.C.= 40.1%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.200	0.240	0.320	0.460	0.590	0.690	0.970	1.090
2A	0.310	0.370	0.450	0.560	0.620	0.720	0.850	1.570
3A	0.190	0.270	0.350	0.390	0.530	0.600	0.980	1.770
4A	0.220	0.400	0.350	0.440	0.460	0.470	0.710	1.220
5A	0.200	0.280	0.360	0.430	0.520	0.580	1.050	1.710
1B	0.190	0.300	0.360	0.450	0.500	0.630	0.850	1.230
2B	0.220	0.310	0.370	0.430	0.510	0.590	0.750	1.240
3B	0.240	0.330	0.350	0.360	0.430	1.460	0.700	1.070
4B	0.190	0.270	0.350	0.380	0.440	0.490	0.830	1.550
5B	0.220	0.310	0.370	0.390	0.410	0.480	0.650	1.030
S.e.d.(a)	0.0835	0.0751	0.0707	0.0681	0.0889	0.1437	0.2403	0.3234
S.e.d.(b)	0.0798	0.0776	0.0734	0.0634	0.0765	0.1278	0.1958	0.3274

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.6 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 10 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.314	0.406
Reduced	0.312	0.304

S.e.d.(a) = 0.0285
S.e.d.(b) = 0.0347
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.7 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 10 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	0.300	0.360
2	0.340	0.270
3	0.290	0.375
4	0.390	0.360
5	0.245	0.410

S.e.d. = 0.0549
Significant at P = 0.05

Table 4.8 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 15 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.364	0.456
Reduced	0.366	0.360

S.e.d.(a) = 0.0263
S.e.d.(b) = 0.0328
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.9 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 15 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	0.420	0.340
2	0.310	0.410
3	0.425	0.350
4	0.480	0.350
5	0.415	0.365

S.e.d.(a) = 0.0480
S.e.d.(b) = 0.0519
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.10 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 20 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.410	0.538
Reduced	0.456	0.402

S.e.d.(a) = 0.0376
S.e.d.(b) = 0.0284
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.11 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 20 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	0.460	0.455
2	0.395	0.495
3	0.475	0.375
4	0.565	0.410
5	0.475	0.410

S.e.d.(a) = 0.0512
S.e.d.(b) = 0.0448
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.12 Effect of penetration resistance (MPa) of different sowing methods and two seed rates at 20 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	0.415	0.500
2	0.525	0.365
3	0.380	0.470
4	0.460	0.515
5	0.385	0.500

S.e.d. = 0.0448
Significant at P = 0.001

Table 4.13 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 25 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.470	0.626
Reduced	0.544	0.458

S.e.d.(a) = 0.0568
S.e.d.(b) = 0.0342
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.14 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 25 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	0.530	0.545
2	0.505	0.565
3	0.540	0.480
4	0.630	0.450
5	0.535	0.465

S.e.d.(a) = 0.0706
S.e.d.(b) = 0.0541
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.15 Effect of penetration resistance (MPa) of different sowing methods and two seed rates at 25 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	0.505	0.570
2	0.605	0.465
3	0.475	0.545
4	0.510	0.570
5	0.440	0.560

S.e.d. = 0.0541
Significant at P = 0.05

Table 4.16 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 30 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.578	0.762
Reduced	0.612	0.530

S.e.d.(a) = 0.0871
S.e.d.(b) = 0.0572
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.17 Effect of penetration resistance (MPa) of different sowing methods and two seed rates at 30 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	0.670	0.660
2	0.735	0.530
3	0.550	0.760
4	0.530	0.655
5	0.490	0.625

S.e.d. = 0.0904
Significant at P = 0.05

Table 4.18 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 40 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.766	1.018
Reduced	0.912	0.756

S.e.d.(a) = 0.1646
S.e.d.(b) = 0.0876
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

With 50cm depth of penetration in different tillage practices, there was a significant difference between sowing methods and tillage systems (**Table 4.19**).

Probably, the effect of seed rates on soil penetration resistance within different penetration depths of 10, 15, 20, 25, 30, 40 and 50cm were due to the soil moving into deep cracks in the cultivated plots of treatments during the seeding operation or being carried by irrigation water into the cracks after wetting and swelling or drying and shrinking. However the penetrometer was always used when the soil was at field capacity moisture level.

In the same experiment the effect of The Recommended and Reduced Tillage Systems on penetration resistance values (MPa) at 8 weeks after sowing are shown **in Tables 4.20 and 4.21**. Results obtained for soil penetration resistance at 15cm of penetration, showed significant differences between tillage systems and seed rates (**Table 4.22**) and between sowing methods and tillage systems (**Table 4.23**). With 25cm depth of penetration within different tillage treatments, there was significant difference between tillage systems and seed rates (**Table 4.24**).

In the same experiment the effect of The Recommended and Reduced Tillage Systems on penetration resistance values at 13 weeks after sowing, (at the end of the growing season). For more details, see Appendix, **Tables 4 and 5**. Results obtained for soil penetration resistance at 5, 10, 15, 20, and 30cm depths of penetration in different tillage treatments, showed significant differences only between tillage systems and seed rates. For more details, see Appendix, **Tables 6 to 10**. Also, penetration resistance values were increased according to the depth of penetration. This is most probably due to the re-setting of soil particles and also, the presence of crop roots. (13 weeks after sowing) on the upper layer (5-30cm depth).

The results obtained showed no significant differences at the other depths of penetration within different treatments. Also the values of penetration resistance in general increased gradually.

This might possibly have been due to the re-setting of soil particles due to the application of flooding irrigation.

Table 4.19 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 50 cm depth of penetration after the second irrigation (M.C.= 40.1%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	2.030	1.160
2	1.450	1.405
3	1.950	1.420
4	1.535	1.385
5	1.115	1.370

S.e.d.(a) = 0.2257
S.e.d.(b) = 0.2315
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.20 Effect of penetration resistance (MPa) of the recommended tillage System and different sowing methods at 8 weeks after sowing (M.C.= 37.4%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.3700	0.4300	0.5400	0.7400	0.9200	1.070	1.310	1.660
2A	0.3500	0.4500	0.5400	0.6900	0.9100	1.020	1.300	1.580
3A	0.3300	0.4100	0.5000	0.6700	0.9300	1.110	1.410	1.720
4A	0.3100	0.3600	0.4400	0.6400	0.9100	1.040	1.380	1.680
5A	0.3300	0.3800	0.4700	0.6700	0.9200	1.090	1.370	1.700
1B	0.4000	0.4600	0.5800	0.7200	0.9000	1.050	1.380	1.700
2B	0.3400	0.4400	0.5900	0.7500	0.9700	1.130	1.410	1.670
3B	0.3400	0.4200	0.5200	0.7600	0.9500	1.110	1.370	1.700
4B	0.3600	0.4400	0.5300	0.7500	0.9500	1.130	1.340	1.730
5B	0.3300	0.4500	0.5700	0.7500	0.9800	1.130	1.400	1.690
S.e.d.(a)	0.02720	0.04177	0.04060	0.05054	0.03772	0.0699	0.0688	0.0692
S.e.d.(b)	0.02771	0.04341	0.04082	0.05167	0.03786	0.0684	0.0718	0.0708

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.21 Effect of penetration resistance (MPa) of the reduced tillage system and different sowing methods at 8 weeks after sowing (M.C.= 37.4%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.2600	0.4000	0.5600	0.7200	0.9000	1.360	1.890	2.340
2A	0.2500	0.4000	0.5700	0.7300	0.9800	1.410	2.050	2.380
3A	0.2300	0.3900	0.6100	0.7300	0.9600	1.410	2.050	2.320
4A	0.2500	0.4100	0.6000	0.7400	1.0000	1.440	1.930	2.370
5A	0.2500	0.4200	0.6700	0.7800	1.0300	1.520	2.010	2.410
1B	0.2300	0.4000	0.5900	0.7300	0.9100	1.430	1.910	2.390
2B	0.2700	0.4100	0.5700	0.7500	0.9000	1.410	2.050	2.360
3B	0.2400	0.4000	0.5800	0.7100	0.9000	1.420	2.030	2.490
4B	0.2600	0.4200	0.6000	0.7500	1.0200	1.390	1.920	2.350
5B	0.2800	0.4200	0.6100	0.7500	0.9400	1.370	1.900	2.480
S.e.d.(a)	0.02720	0.04177	0.04060	0.05054	0.03772	0.0699	0.0688	0.0692
S.e.d.(b)	0.02771	0.04341	0.04082	0.05167	0.03786	0.0684	0.0718	0.0708

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.22 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 15 cm depth of penetration at 8 weeks after sowing (M.C.= 37.4%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.4980	0.5580
Reduced	0.6020	0.5900

S.e.d.(a) = 0.01774
S.e.d.(b) = 0.01826
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.23 Effect of penetration resistance (MPa) of different tillage systems and sowing methods at 15 cm depth of penetration at 8 weeks after sowing (M.C.= 37.4%)

	Tillage System	
Sowing Methods	Recommended	Reduced
1	0.5600	0.5750
2	0.5650	0.5700
3	0.5100	0.5950
4	0.4850	0.6000
5	0.5200	0.6400

S.e.d.(a) = 0.02854
S.e.d.(b) = 0.02887
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.24 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 25 cm depth of penetration at 8 weeks after sowing (M.C.= 37.4%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.9180	0.9500
Reduced	0.9740	0.9340

S.e.d.(a) = 0.01662
S.e.d.(b) = 0.01693
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: for comparing means with same tillage system.

The results indicate that tillage operations decreased penetration strength, most probably because of soil loosening. This agrees with the findings that subsoiling to more than 45cm depth improved infiltration rate (Swain, 1975; Schindler and Muller, 1987). Results obtained, however, were contradictory to Wilkinson (1976) who reported that the infiltration rate of two tropical soils was found to decrease after ploughing and tillage operations.

Lowry *et al*, (1970) tested the penetration resistance technique as an indicator of the mechanical properties of soils in relation to cultivation operations. They found that penetration resistance is one of the methods to evaluate soil structure, today it is the most common system due to its facility and the immediacy of the data collected, its low cost and the independence of the measured parameter from the terrain typology.

4.2 Plant Parameters

Different tillage practices used and their effect on the measured crop growth, development and yield response under hot irrigated environment during the study were assessed by following The Third International Heat Stress Genotype Experiment 1991/92 (IHSGE - CIMMYT).

4.2.1 Plant Density and Crop Development

Experiment 1, the effects of different depths of disc harrowing on emergence (2 weeks after sowing), and development of crop at five leaves and flowering stages are shown in **Tables 4.25, 4.26 and 4.27.** No significant differences between different depths of disc harrowing were observed, except at the flowering stage. There were significant differences in plants/m^2 (P = 0.05); shoot dry weight (P=0.05) and shoot:root ratio (P=0.05) which are shown in **Figures 4.14, 4.15 and 4.16** respectively.

It seems that the uneven emergence of plants/m^2 at two weeks after sowing was due to lack of levelling and uneven distribution of water when flooding irrigation was applied. However, plants/m^2 were improved at 5 leaves and flowering stages due to the subsequent irrigation and also the break down of surface clods allowing shoots to appear above the soil surface more easily.

Table 4.25 Effect of different depths of disc harrowing on wheat establishment - two weeks after sowing

Harrowing Depth (cm)	Emergence (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
5	235.0	19.9	3.60	5.4
10	245.0	25.3	7.05	3.5
15	193.0	11.4	1.80	6.9
20	208.0	14.9	1.00	15.3
25	188.0	12.3	3.57	7.4
S.e.d.	43.8	9.53	1.044	4.98

Table 4.26 Effect of different depths of disc harrowing on wheat establishment - at 5 leaves stage

Harrowing Depth (cm)	Plant Density (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
5	245.0	187.0	57.9	3.25
10	288.0	222.0	46.5	5.12
15	223.0	165.0	69.8	3.05
20	245.0	203.0	47.2	4.37
25	265.0	209.0	44.3	5.00
S.e.d.	71.0	64.7	19.86	0.650

Table 4.27 Effect of different depths of disc harrowing on wheat establishment - at flowering stage

Harrowing Depth (cm)	Plant Density (Plants/m^2)	Shoot Dry Weight (g)	Root Dry Weight (g)	Shoot:Root Ratio
5	310.0	473.0	30.3	15.80
10	445.0	601.0	32.6	18.52
15	458.0	593.0	33.5	17.70
20	400.0	563.0	31.5	18.02
25	375.0	532.0	45.4	12.95
S.e.d.	54.7	55.1	6.42	1.906

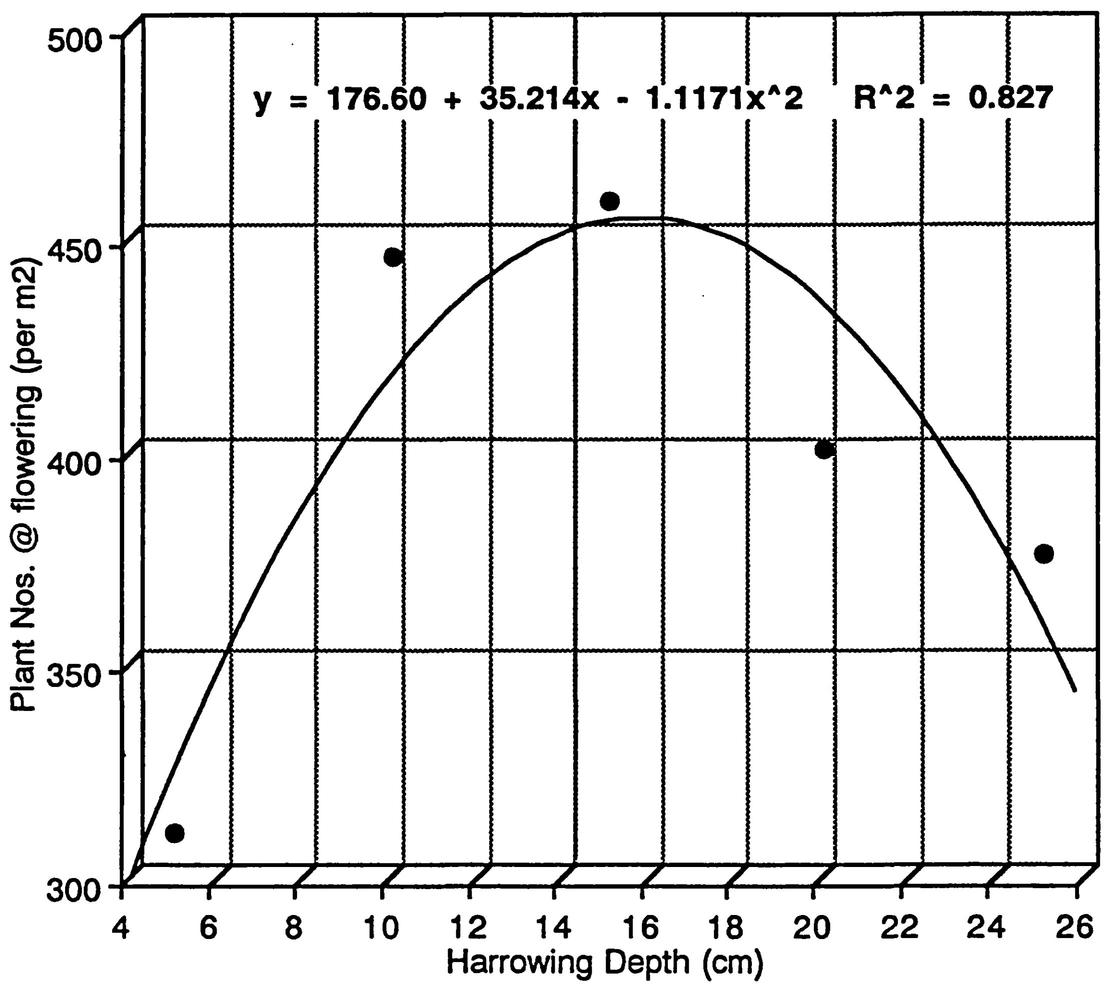


Figure 4.14 Effect of different depths of disc harrowing on wheat establishment at flowering stage.

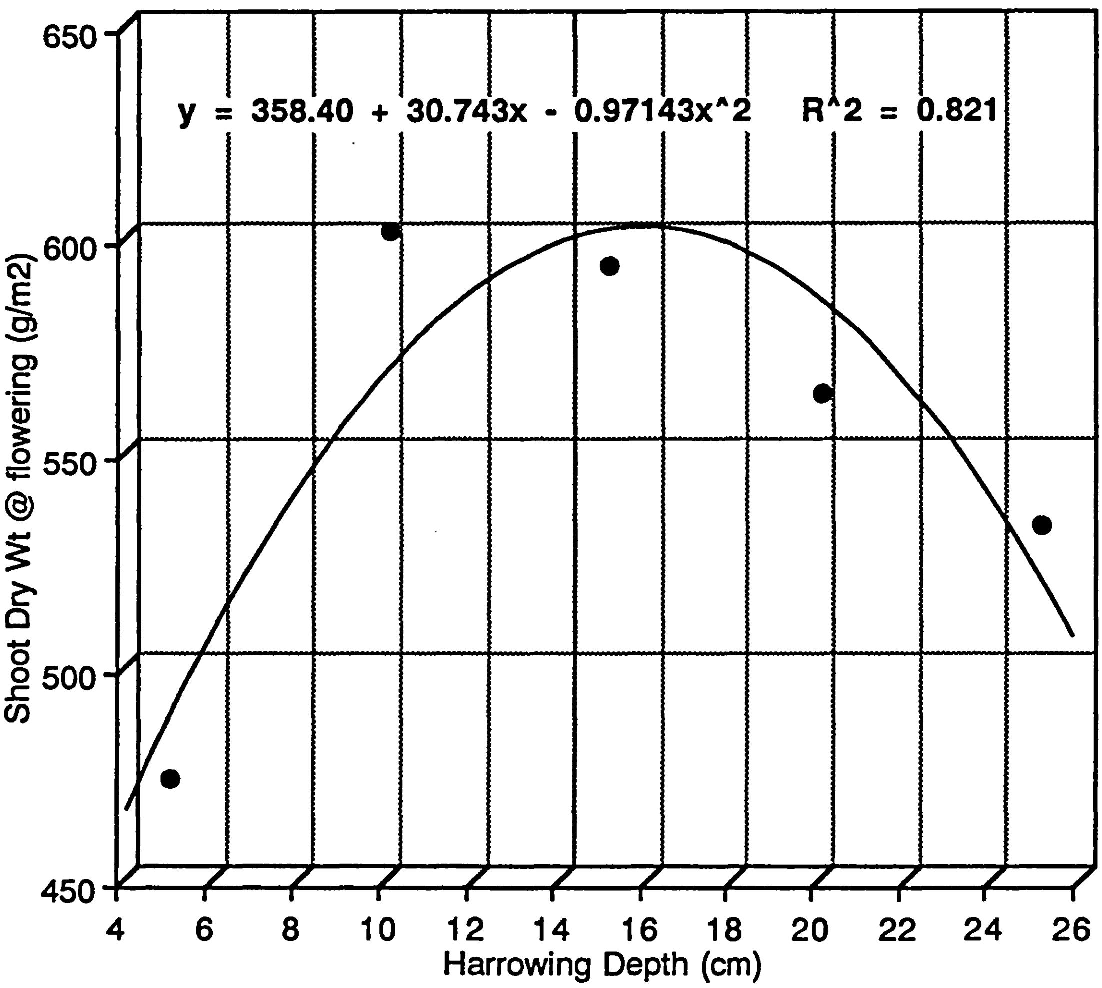


Figure 4.15 Effect of different depths of disc harrowing on shoot dry weight at flowering stage.

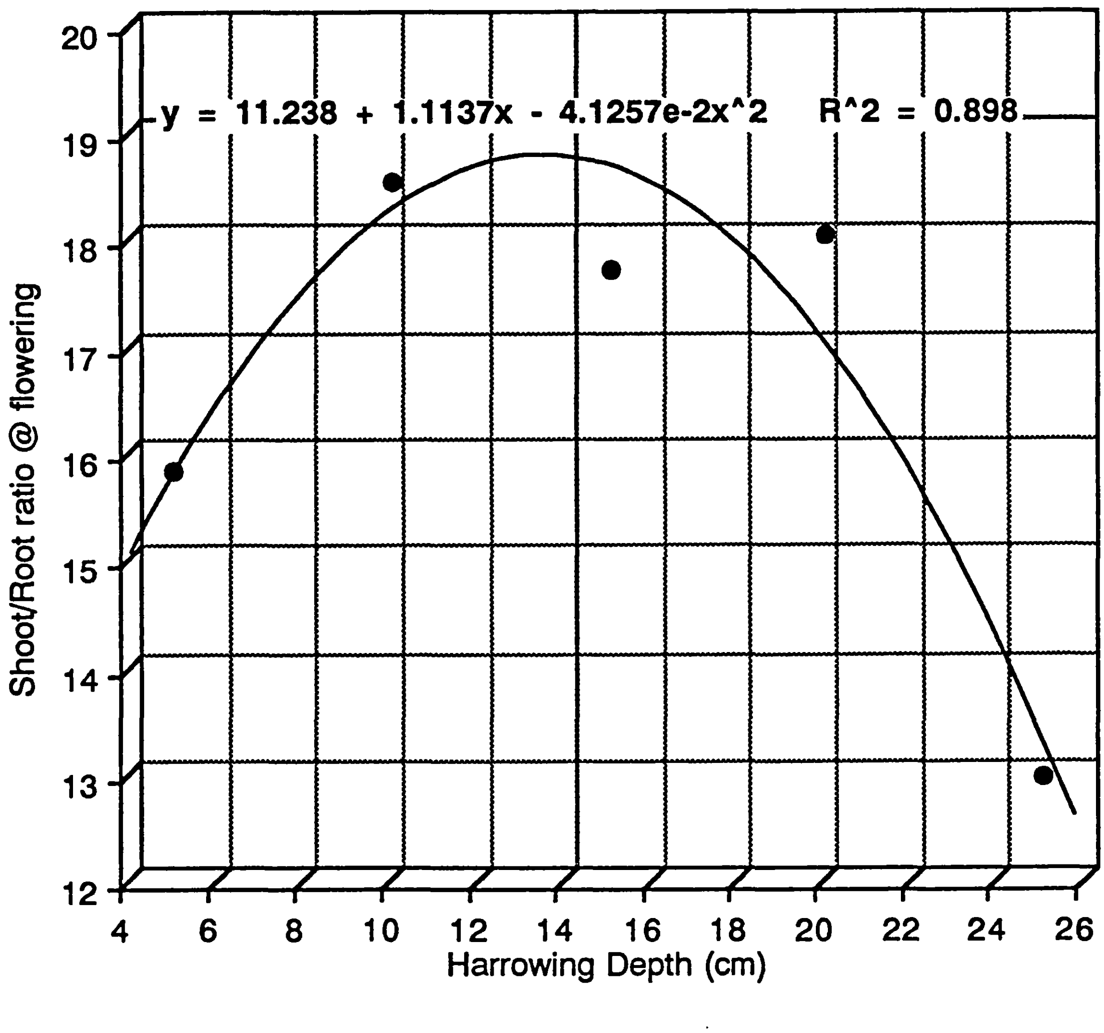


Figure 4.16 Effect of different depths of disc harrowing on shoot:root ratio at flowering stage.

Experiment 2 the effect of The Recommended and Reduced Tillage Systems with different sowing methods at two weeks after sowing are shown in **Tables 4.28 and 4.29**. There were significant differences between treatments at two weeks after sowing. These included sowing methods and tillage systems on shoot dry weight (**Table 4.30**); sowing methods and seed rates on shoot dry weight (**Table 4.31**); tillage systems and seed rates on root dry weight (**Table 4.32**); sowing methods and seed rates on root dry weight (**Table 4.33**); sowing methods and tillage systems on shoot:root ratio (**Table 4.34**); sowing methods and seed rates on shoot:root ratio (**Table 4.35**). The results obtained showed that treatment 1A (seed drill - 20cm on flat land with 60 kg/f seed rate) gave the highest values on shoot dry weight (g/m^2) at two weeks after sowing, which was nearly 30% higher compared with the other different sowing methods and seed rates within tillage practices, the differences between the other treatments were slight. This was probably due to more soil moisture after the first flooding irrigation on the flat drilling treatment.

However, treatment 1B (seed drill - 20cm on flat land with 40 kg/f seed rate) gave the highest values on root dry weight. This was possibly due to the fact that at emergence stage (only two weeks after sowing) seedlings were small and it was difficult to distinguish the beginning of stems. On shoot:root ratio the highest values were obtained with treatments 5B (wide level disc sowing on 120cm beds with 40 kg/f seed rate), (**Tables 4.34 and 4.35**). This was probably due to water control over the field on The Reduced Tillage System preventing seeds from being washed from the soil surface.

The effect of different tillage systems with different treatments at the five leaves and flowering stages were not significant (See Appendix, **Tables 11 to 14**). Many researchers (Cooper, 1958; Leonard and Head, 1958; Head, 1967; Kramer, 1969; and Taylor and Arkin, 1981) have reported in interdependence of plant roots and shoots. Pande and Bhan (1966), Mech et al. (1967), and Mahmoud (1985) found that deep ploughing to depth 28cm or more has an influential effect on crop growth due to its effect on soil structure.

This is an absolute contrast under the Gezira conditions, due to the shallow fertile layer and the high cost of the deep cultivation required. Also wheat roots are usually only at shallow depths.

Table 4.28 Effect of recommended tillage system with different sowing methods on wheat establishment at two weeks after sowing

Treatment	Emergence (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	343.3	9.133	2.567	3.567
2A	323.3	6.367	2.500	2.533
3A	316.7	6.367	2.467	2.567
4A	320.0	6.000	3.267	1.833
5A	310.0	6.400	3.467	1.833
1B	216.7	9.100	2.967	3.100
2B	213.3	3.733	1.367	2.733
3B	200.0	7.200	2.100	3.433
4B	210.0	7.567	2.300	3.333
5B	206.7	5.167	1.600	3.233
S.e.d.(a)	19.48	0.4210	0.2141	0.1705
S.e.d.(b)	18.95	0.4113	0.2166	0.1681

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.29 Effect of reduced tillage system with different sowing methods on wheat establishment at two weeks after sowing

Treatment	Emergence (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	313.3	8.233	2.300	3.600
2A	316.7	5.300	1.433	3.733
3A	303.3	6.800	2.300	2.967
4A	300.0	6.600	2.133	3.133
5A	306.7	7.033	2.267	3.100
1B	240.0	5.833	3.100	1.900
2B	216.7	6.067	1.233	4.967
3B	233.3	5.467	1.400	3.967
4B	226.7	6.533	1.500	4.367
5B	236.7	8.833	1.733	5.100
S.e.d.(a)	19.48	0.4210	0.2141	0.1705
S.e.d.(b)	18.95	0.4113	0.2166	0.1681

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.30 Effect of different tillage practices with sowing methods on shoot dry weight at two weeks after sowing

	Tillage System	
Sowing Methods	Recommended	Reduced
1	9.117	7.033
2	5.050	5.683
3	6.783	6.133
4	6.783	6.567
5	5.783	7.933

S.e.d.(a) = 0.3044
S.e.d.(b) = 0.2908
Significant at P = 0.001.
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.31 Effect of different sowing methods with two levels of seed rate applied on shoot dry weight at two weeks after sowing.

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	8.683	7.467
2	5.833	4.900
3	6.583	6.333
4	6.300	7.050
5	6.717	7.000

S.e.d. = 0.2908
Significant at P = 0.001

Table 4.32 Effect of different tillage practices with two levels of seed rate applied on root dry weight at two weeks after sowing.

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	2.853	2.067
Reduced	2.087	1.794

S.e.d.(a) = 0.0912
S.e.d.(b) = 0.0969
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 4.33 Effect of different sowing methods with two levels of seed rate applied on root dry weight at two weeks after sowing.

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	2.433	3.033
2	1.967	1.300
3	2.383	1.750
4	2.700	1.900
5	2.867	1.667

S.e.d. = 0.1532
Significant at P = 0.001

Table 4.34 Effect of different tillage systems with sowing methods on shoot:root ratio at two weeks after sowing.

	Tillage System	
Sowing Methods	Recommended	Reduced
1	3.333	2.750
2	2.633	4.350
3	3.000	3.467
4	2.583	3.750
5	2.533	4.100

S.e.d.(a) = 0.1221
S.e.d.(b) = 0.1189
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 4.35 Effect of different sowing methods with two levels of seed rate applied on shoot:root ratio at two weeks after sowing.

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	3.583	2.500
2	3.133	3.850
3	2.767	3.700
4	2.483	3.850
5	2.467	4.167

S.e.d. = 0.1189
Significant at P = 0.001

4.2.2 Yield and Components

Experiment 1, effect of different depths of disc harrowing on yield and components there were no significant differences observed (See Appendix **Table 15**).

Experiment 2, effect of Recommend and Reduced Tillage Systems with different treatments on yield and components, there were no significant differences, except with the number of grains per head and harvest index. Treatment 5 (wide level disc sowing on 120cm beds) with Reduced Tillage System gave the highest value on the number of grains per head, while the same treatment gave 14.67 with 60 kg/f seed rate and slightly lower (13.15) with 40 kg/f seed rate (See Appendix **Tables 16 to 19**).

However, treatment 2 (wide level disc on flat land) gave the highest value on the number of grains per head. Treatment 2B (wide level disc on flat land) with 40 kg/f seed rate gave the highest value on Harvest Index, however, there were only slight differences in values with treatment 5 (wide level disc sowing on 120cm beds) with the same seed rate level and treatment 1 (seed drill on flat land) with 60 kg/f seed rate (see Appendix, **Table 20**). This possibly was due to the better control of irrigation when sown in wide beds (120cm wide) with Reduced Tillage.

4.3 Machine Parameters

4.3.1 Effect of Different Disc Harrowing Speeds on Aggregate Sizes

The mean weight of different aggregate sizes distributed on the soil surface, at different disc harrowing speeds, for the first disc harrowing carried out at 10cm depth is shown in Appendix **Table 21**. Regression analysis showed there was no significant relationship between Actual Speeds and mean weight of different aggregate sizes produced. This is shown in the Appendix (**Figures 3 to 9**). This was probably due to the low soil moisture content (5.6%) and the fact that the maximum disc harrowing depth was 10cm (surface layer) and also to the presence of many deep cracks which were in the ground after the harvesting of cotton.

4.3.2 Machine Performance and Field Operation Costs

Different measurements of disc harrowing operations at different depths (Experiment 1) are shown in **Figure 4.17.** Results showed that increasing the depth of harrowing caused increased power requirement and cost. Cost is very considerable and caused by the high cost of diesel fuel and running cost of the tractor.

However, the grain yield slightly increased at 15cm and 20cm (over 5cm depth) while the best yield was obtained at 10cm depth.

Machine measurements for different tillage practices are shown in **Table 4.36.**

Results showed that the wide level disc type drill required a lower draught force, had lower operation cost and also a higher field capacity compared with the conventional seed drill which was slower in turning. Also, results indicated that the Reduced Tillage System (ridging and ridge splitting) was achieved at minimum cost. The cost was approximately one half of the Recommended Tillage System, (disc harrowing twice) which also requires more skill from the operator.

The results obtained from machine parameters are in accordance with the findings of Cary and Rasmussen (1979); O'Connell (1975), and Ahmed and Haffar (1993) who also state that there were considerable variations in the methods used to assess machine performance among the different treatments.

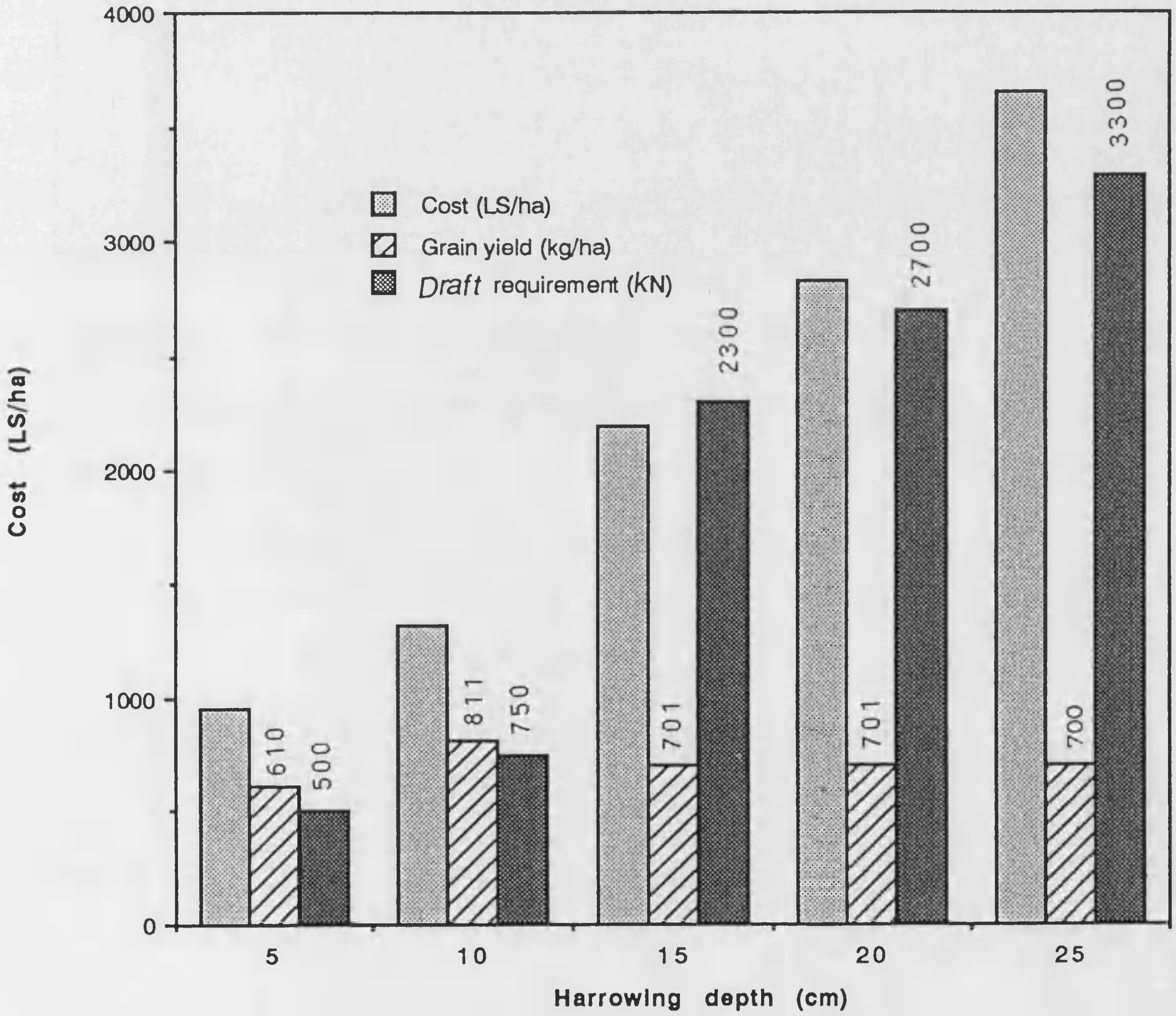


Figure 4.17 Effect of harrowing depths on wheat yield and operation cost (Season 1993/94).

Table 4.36 Power requirements and cost of operation of different implements and operations (Season 1993/94).

Equipment and Operation	Power Requirement (Draught Force) (kN)	Fuel Consumption (l/ha)	Field Capacity (ha/h)	Operation Cost (LS/ha)
First disc harrowing (at 10 cm depth)	750	5.31	1.7	1320.0
Second disc harrowing (at 10 cm depth)	700	4.92	1.9	1190.4
Ridging	350	4.48	2.1	730.3
Ridge Splitting	328	4.27	2.6	675.1
John Deere-8200 Seed drill	320	4.28	1.8	814.9
Wide Level Disc type drill	315	3.75	2.2	712.0

£1 = LS 510 (1993)

5.0 CONCLUSIONS

5.1 Effects on Soil Physical Conditions

The results presented here demonstrate that the physical properties of the soil, such as aggregate size and penetration resistance are greatly influenced by the tillage system used. Of particular note is the observation that the reduced tillage system (i.e. using ridgers rather than disc harrows) could achieve satisfactory aggregate size, aided by natural drying/wetting cycles and soil breakdown by the first flooding irrigation. Ridges of 60cm between centres appeared most suitable. When ridges were wider apart, thus producing a 120cm bed, water was not spread evenly due to the land not being level, to the deep cracks present and to the swelling and shrinking properties of the Gezira vertisols.

For all treatments, penetrometer values generally increased over the length of the experiment due to the resettling of soil particles at different depths following irrigation.

5.2 Effect of Disc Harrowing Speeds

Regression analysis showed that there was no significant relationship between forward speeds and mean weight of different aggregate sizes on the soil surface after the first harrowing, which was most probably due to the low soil moisture content (5.6%). However, clod breakdown could be achieved with the benefit of natural conditions leading to weathering and to irrigation water.

5.3 Effect of Disc Harrowing Depth

Different depths of disc harrowing did not significantly affect yield, but the highest yield appeared to be with 10cm depth of harrowing. This may be because the wheat roots only exploited a shallow depth of soil.

5.4 The Reduced Tillage System

This 10cm depth of cultivation could be achieved by the practices of ridging and ridge splitting at 10-15cm depth using an ordinary ridger (using a ridger also enables the seed-bed to be produced at lower cost and makes use of a readily available implement which is used for other operations).

5.5 Effect on Yield

Although the different tillage systems did not influence final grain yield, they did impact upon establishment and plant growth as seen two weeks after sowing, at the five leaves stage, the flowering stage, number of grains per ear and harvest index. The reasons why tillage effects on plant establishment and growth were not reflected in yield may have been due to higher temperatures during the grain filling period (see Appendix, **Figure 3**).

5.6 Weed Control

The control of weeds on the surface could be aided by planting local fodder crops such as abousabeen which only takes about two months to mature.

5.7 Effect of Irrigation and Lack of Levelling

It was observed that plant density at emergence was mainly affected by lack of levelling and uneven distribution of flooding water. This was particularly true of the first excessive water application after sowing. This irrigation involved large volumes of water because much was required to fill the soil cracks. The large volume of water, however, may also have contributed to seed washing out, waterlogging and hence poor germination. This was true even with seed drilled at a depth of 7cm with the wide level disc type drill.

5.8 Effect of Sowing Equipment

Results obtained showed that the wide level disc type drill had a lower operating cost and higher field capacity compared with the conventional seed drill which was slower in turning and required more draught force.

5.9 Effect of Reduce Tillage System on the Cost of Seed-bed Production

Results indicate that the reduced tillage system (ridging and ridge splitting) had an operating cost of approximately one half of the tillage system recommended by the Agricultural Research Corporation at Wad Medani, Sudan.

PART TWO - MOROCCO

6.0 LITERATURE REVIEW

6.1 Location - Kingdom of Morocco

The kingdom of Morocco is located in north-west Africa. It is bordered to the North by the Mediterranean Sea, to the South by Mauritania, to the East by Algeria and to the West by the Atlantic Ocean. The Moroccan coastline is 3,500 km long. Area: 710,850 km^2 (**Figure 6.1**).

6.2 Climate

Morocco's climate is semi-tropical. It is affected by the Mediterranean sea in the North, the Atlantic Ocean in the West and North-west and by the continental climate in the interior. The Atlas mountains region is wet, with frequent snow, while the South is characterised by a hot desert climate. The main rivers in Morocco are shown in **Table 6.1.**

6.3 Agriculture Sector

Agriculture is one of the most important sectors of economic activity in Morocco. Nearly 50% of the working population are engaged in agriculture.

There are seventy operational dams within a total annual retention capacity of ten billion cubic metres. The M'Jaara and Hachef dam projects will bring the retention capacity up to 14 billion cubic metres. The goal targeted by public authorities is to irrigate one million hectares by the end of the century in order to secure self-sufficiency in cereals and food products. The overall irrigated area stands at 800,000 hectares.

The main achievement of the last few years was a marked improvement in agricultural production, but hard drought for the last four years, (the 1995/96 growing season was especially hard) has had a bad effect on production. **Table 6.2** shows production levels of the major cereals before the run of drought years. This represented a major increase over that achieved from 1988-1991 (76 million quintars), 1981-1987 (45 million quintars) and 1970-1980 (43 million quintars).

Figure 6.1 Map of the Kingdom of Morocco.

Table 6.1 The main rivers in Morocco

Rivers	Source	Mouth	Length (km)
Draâ	High Atlas	Near Tan Tan	1,200
Oum Rbiâ	Middle Atlas/ High Atlas	Azemmour	600
Sebou	Middle Atlas Rif	Mehdia	500
Moulouya	Middle Atlas High Atlas Rif	Saïdia	450
Tensift	High Atlas	Near Safi	270
Ziz	High Atlas	In the desert	270
Bouregreg	Central massif	Rabat-Salé	250

Table 6.2 The Main Crops in Morocco

1990-1991	Area (Million hectares)	Production (Million quintals)	Quintals per hectare
Durum wheat	1,245	22.2	17.8
Bread wheat	1,397	27.2	19.5
Barley	2,356	32.5	13.8
Corn	0,385	3.4	8.7
Total	5,383	85.3	

Source : ISESCO - Rabat - Morocco. (1994)

6.4 Agriculture in the Semi-Arid Regions of Morocco

Morocco has 8.9 million hectares of cultivatable land of which only about 10% is irrigated. About 20% of this area is kept fallow each year (Ministry of Planning, 1990). Small grain cereals (wheat and barley) are the most important crops in Morocco grown primarily in dry-land farming. Among the food legumes, faba beans, lentils, chickpeas and peas are important crops. The yields of all crops vary considerably from year to year depending upon rainfall amount and distribution. Most significant, however, is that even in climatically good years such as 1990-1991, Morocco is not self sufficient in wheat, barley and maize. The gap between consumption and production is expected to further increase in the long term because the demand for cereals is growing by 2.5% per year, food legumes by 4.5% and vegetables by 3.5%, owing to population increase and improvements in the standard of living (Naanani, 1985). Thus, considerable effort is needed to improve the productivity of dry-land farming systems.

6.4.1 The Progress Towards Mechanisation

Mechanisation of field operations has expanded progressively since 1957 when the Government of Morocco (GOM) initiated an active policy to encourage the use of tractors for tillage. A nation-wide program was launched called 'Operation Labour' (Ploughing operation) in 1957/58 to plough fields with tractor drawn ploughs (Rami Yahiaoui, 1985). This program was largely implemented through government-equipped extension service centres. The tillage operation ran five years and covered approximately 200 thousand hectares. Cereal grain yields in that area increased by 45 - 60%, which was taken as a success of the 'Operation Labour' Rami Yahiaoui, (1985).

In 1966, the GOM started encouraging farmers to buy farm equipment by lowering the tax on locally manufactured items. Subsequently, in 1969, the GOM promoted the importation and local marketing of tractors and other farm equipment by establishing a lower import tariff of 25%, which was reduced to 10% in 1973, and abolished in 1977 (Ministry of Agriculture, 1987). The GOM also introduced subsidies varying from 10-35% on tractor mounted implements depending upon the type of implement and individual or group ownership (Ministry of Agriculture, 1991).

Agricultural mechanisation has played a significant role in increasing food production in Morocco. Land preparation and sowing cereals using tractor-drawn machinery and harvesting with combines improved labour productivity leading to an expansion of area in cereal crops, particularly wheat and barley. However, the production of other grain crops has not been mechanised to the same degree. Labour constraints and lack of availability of appropriate mechanisation for specific needs of farmers continues to limit the production of food legumes in general and cereals under certain situations, (Bansal *et al*, 1994).

Bansal *et al* (1983) demonstrated the improvements that could be achieved by using a seed drill at four locations in Morocco (**Table 6.3**). The seed drill presents a major investment, especially for farmers who do not already own other farm equipment of significant value. Many farmers, particularly those operating medium and small sized farms, are able to rent tractors and combines for certain operations to save time and lower costs. However, there are still many gaps in the mechanisation of farm operations. For example, sowing seed by hand broadcasting is a wasteful method, but very few farmers use seed drills. Growth in the sales of equipment for planting, fertiliser application, inter-row weed management and spraying has remained very slow (Bansal *et al*, 1994).

An inventory of farm equipment obtained from a survey of 84 tractor owners in the Settat region (Riddle and Moore, 1990) found the offset disc harrow was the most preferred implement. Each farmer had at least one offset disc harrow per tractor and used it as a multi-purpose implement for both shallow cultivation and/or for covering seed after hand broadcasting. Forty-eight percent of the sampled farmers owned no other implement and only three of the 84 farmers had tractor mounted grain drills.

Table 6.3 Summary of wheat yields (kg/ha) obtained from on-farm experiments at four locations, 1990-1991.

Sowing method	Seeding rate (kg/ha)	Locations I	II	III	IV	Average	Percent increase over farmer's method
		----- grain yields (kg/ha) ----					
Seed drill	120	2880	1966	2690	1686	2305	7.1
Farmer's method	180	2426	1926	2663	1596	2153	

Source: Bansal *et al*, 1993.

6.4.2 Prospects for Farm Mechanisation in Morocco

Bansal *et al* (1994) emphasised that research should be re-directed towards agricultural mechanisation, particularly for the development of equipment and should be adapted to local conditions and needs. Researchers should also work more closely with the machinery manufacturing industry to solve problems related to equipment design, quality control and field evaluation. Agricultural engineers have to play a bigger role in technology transfer activities such as training of extension personnel and on-farm demonstrations of new equipment. Only through these efforts will farmers be able to integrate more mechanisation into their farming practices. This will also help create a demand for new farm equipment and other research outputs. For this purpose, mechanisation programmes in Morocco need greater support from the government and private sources.

6.5 Tillage Option for Water Management and Crop Rotation Under Semi-Arid Conditions

In the semi-arid tropics, characterised by a long dry period (6-8 months) and one short rainy season, rainfall at the onset of the wet season is crucial to establishing a crop. However, rainfall impact on the soil surface is high and strongly affects runoff and erosion.

Soil tillage may be used for seed-bed preparation, weeding or to enhance the infiltration of water in the soil. Bourarach and Oussible (1995) studied the soil management in arid and semi-arid areas of Morocco. They found that where yields of cereal crops were low the plant cycle was not matching the rain cycle, the rain falling at times when it would be of little use to the plant. The rain cycle varies from year to year. Ouattar and Ameziane (1989) reported that poor germination and emergence of cereal crops in Morocco was due to the inconvenient matching of rain, sowing time and soil conditions. To alleviate the influence of poor establishment most farmers increase the seed rate by 20-25% depending on the state of the seed-bed, lateness of sowing and low germination caused by poor storage of seed. They also mention that crop rotation and the use of registered seed could contribute to weed and disease control. The use of chemicals is not economical and many farmers do not wish to use chemicals at all.

Crop rotation experiments on bread wheat were conducted for 6 years on Andosols and Vertisols representative of wheat production zones in south-eastern Ethiopia (Gorfu and Tanner,1991). Results indicated that on Andosols the largest yield was after faba bean (1366kg/ha). On Vertisols, first wheats in 2-year rotational systems out-yielded second wheats by an average of 1085kg/ha. There was no response to phosphate fertiliser at either site, but there was a highly significant linear response to nitrogen.

Olugbemi (1991) indicated some major problems facing wheat production in Nigeria which is entirely produced under irrigation with the average yield range of 1.0-1.5 t/ha. The highlighted problems included unsuitability of climatic conditions, non-adoption by farmers of recommended agronomic and management practices such as appropriate seed and fertiliser rates and good water management. These problems are also associated with sowing of mixed seeds and late sowing dates due primarily to the late removal of rice and cowpea. Also wheats usually develop and ripen very quickly under the prevailing high temperatures, resulting in poor yields.

In Romania, Sin and Petcu (1992) found in a crop rotation, early previous crops for winter wheat favoured a storing of soil water from summer rainfall, with beneficial effects on the growth and the yield of wheat. This positive effect can only be obtained by a suitable tillage method: Summer ploughing immediately after the harvest of the proceeding crop and keeping the ploughed land free of weeds until winter wheat seeding. It seems that in Spring and early Summer an excessive loosening of soil favours water loss through evaporation, having negative consequences on the emergence and density of the following crop. The use of fallow or of crops harvested early in the summer improved the soil moisture regime in the cropping system under a hot environment. Also storage of the water in the soil makes it available to plants during the growing season.

In Holland, Hoogmoed *et al* (1992) carried out experiments with two types of soil tillage, tillage aimed at water conservation by increasing infiltration and/or surface roughness and tillage aimed at weed control. Results showed that water conservation tillage has a very small yield conserving effect because of the limitations set by the nutrient status. Elimination by tillage of the competition by weeds had a larger effect on the grain yield of a millet crop.

6.6 Soil Compaction and Physical Properties

Oliveira and Balbino (1991) studied the response of wheat to soil compaction in mechanised agriculture in Brazil. The study involved combinations of soil preparation implements with basic differences in depth and thickness of compacted layer of oxisol claysoil, with a mean of 82% clay, 12% silt, 6% sand and with 1.92% organic matter. The effect of different treatments to an impact penetrometer are shown in **Figure 6.2.**

The effects of the different systems on soil bulk density are presented in **Table 6.4.** Also the direct and indirect effects of this compaction on root distribution and length, dry matter production at 30 days, and grain yield are shown in **Tables 6.5** and **6.6.** These results showed that wheat crop productivity can be markedly reduced by soil compaction. Compaction is characterised by an increase in soil bulk density and a decrease in pore space as a result of the effect of agricultural activities. Compaction is commonly caused by the use of agricultural implements, but the passage of agricultural vehicles could be reduced to a minimum by using Gantry tractors or tramlines. The presence of compaction within the different tillage systems resulted in a large proportion of the roots of the wheat crop accumulating above the compacted layer where the soil physical and chemical conditions were more adequate.

Bacchi (1976) found that a deeper compacted layer, even if thicker, was not as detrimental to root growth as a superficial layer, but in a study by Oliveira and Balbino (1991) when the compacted layer was deeper, root penetration, shoot dry matter at 30 days, and grain yield were not affected significantly probably because of the greater soil volume explored by the roots. The effects of soil compaction on crop yields is due to the reduced depth and volume of soil explored by the roots, with a resulting reduction in capacity to absorb water and nutrients, as well as an air-filled pore space in the compacted layer below the minimum necessary for root growth (Rosenberg, 1964; Taylor, 1971; Cintra and Mielniczuck, 1983).

- **T1 = Direct seeding (no-till) in both summer and winter.**
- **T2 = Preparation with disks in summer and direct seeding in winter.**
- **T3 = Moldboard plow in both summer and winter.**
- **T4 = Chisel plow in summer, moldboard plow in winter.**
- **T5 = Moldboard plow in summer, direct seeding in winter.**

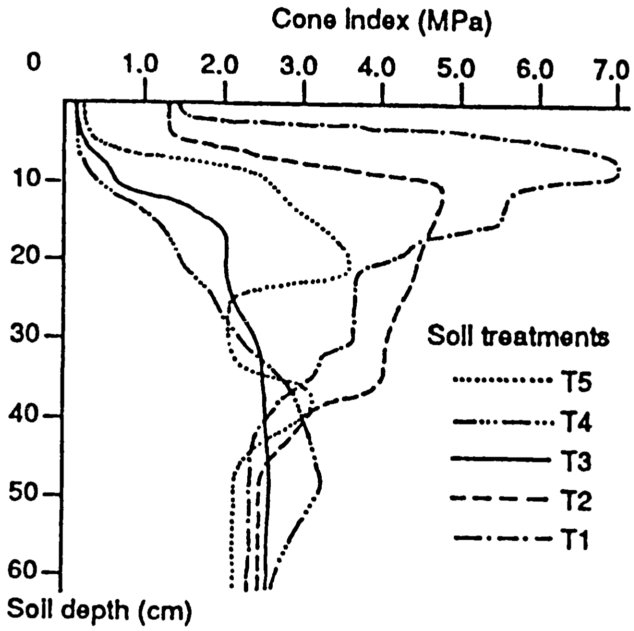


Figure 6.2 Impact penetrometer resistance curves of five soil treatments. OCEPAR, Palontina, 1990.

Table 6.4 Soil bulk density in five treatments with different tillage systems.

Soil depth (cm)	T1	T2	T3 (Treatment, g/cm³)	T4	T5
2-10	1.47	1.40	1.37	1.34	1.40
10-18	1.58	1.56	1.38	1.38	1.36
18-25	1.48	1.49	1.39	1.37	1.39
25-33	1.47	1.41	1.38	1.35	1.36
33-40	1.42	1.35	1.36	1.36	1.39

Table 6.5 Quantity (%) of wheat roots at different soil depths in five treatments with different tillage systems.

Soil depth (cm)	T1	T2	Treatment T3 %	T4	T5
0-5	44	21	24	20	28
6-10	20	35	13	17	25
11-15	10	12	15	15	11
16-20	7	9	13	14	11
21-25	7	7	12	12	8
26-30	5	6	10	8	8
31-35	5	5	7	8	7
36-40	2	5	6	6	6

Table 6.6 Root length, above ground dry matter, and garin yield of wheat in five treatments with different tillage systems.

Treat-ment	Root length[a] (cm/80 cm^3)	Shoot dry matter[a] (g/0.25 m^2)	Grain yield[b] (kg/ha)
T1	19.7	43.5	2262
T2	23.5	43.2	2508
T3	31.5	59.2	3099
T4	27.8	64.5	3186
T5	24.5	55.3	2636

[a] 30 days after germination.
[b] Grain yield in 1989.

Kacemi *et al* (1992) carried out some experiments to study effects of different tillage equipment on some physical properties of clay soil under semi-arid conditions. Results showed that the Dutzi combined machine maintained a constant and smaller bulk density in the upper 20cm compared to other tillage implements. Beyond the 15cm depth, a stubble plough and direct drilling tended to present higher bulk density than other tillage methods. Cone index values (i.e. a measure of penetration resistance) from 0-10cm and 40-50cm were not significant among tillage treatments. However, resistance to penetration from 5cm to 35cm soil depth were significantly different. The mouldboard plough maintained a consistently lower cone index, whereas direct drilling had a consistently higher cone index over the 0-50cm range.

Braunack and Dexter (1990) cited Dorenko (1924) and Kvasnikov (1928) reported maximum wheat yields with seed-beds of 2-3mm aggregates. Jaggi *et al* (1972) concluded that seed-bed of 1-2mm aggregates with a dry bulk density of 1.2-1.3g/cm^3 would give the best wheat grain yield on a clay soil.

Braunack and Dexter (1988) found that the intermediate size aggregates (2-3mm) resulted in earlier emergence and higher wheat yields than with larger aggregates (>4mm) on a loam soil. Finer aggregates (<1mm) tend to restrict aeration and reduce emergence under wetter soil conditions, but result in earlier emergence in drier years (Braunack and Dexter, 1988). Results also showed that dry-mean weight diameter of aggregate was not significantly influenced by the tested tillage methods. These results show that it is impossible to generalize about the optimum aggregate size for wheat yields. It seems that results obtained from experiments conducted under temperate conditions are very different to those obtained under hot irrigated vertisol conditions, particularly when the first flooding irrigation applied causes almost complete collapse of the aggregates.

Ryan *et al* (1992) carried out a three year experiment at Sidi El Aydi Agricultural Research Station, Morocco, to study the effects of machinery traffic on physical parameters of clay soil. The treatments involved uniform once-over compaction with tractors with different weights to give 97, 117 and 241 kiloPascals (kPa). The ground was relatively dry at the surface at the time of compaction and moist beneath. Measurement of infiltration rate with a double-ring infiltrometer indicated differences between treatments (**Figure 6.3**). The two lower compaction levels were similar and markedly different from the control, whilst the highest compaction treatment was similar to, and indeed slightly higher than the control. Soil bulk density measurement (**Figure 6.4**) showed that all compacted treatments had higher bulk density values with depth (10-25cm). The highest recorded value at 0-10cm was from the highest compaction treatment, while penetrometer readings increased with depth (**Figure 6.5**). The pattern was similar for all plots except the medium compaction level, which was consistently higher at depths below 10cm than the control and the other two compaction levels. So it appears that compaction increases bulk density and penetration resistance, and consistently reduces infiltration rate.

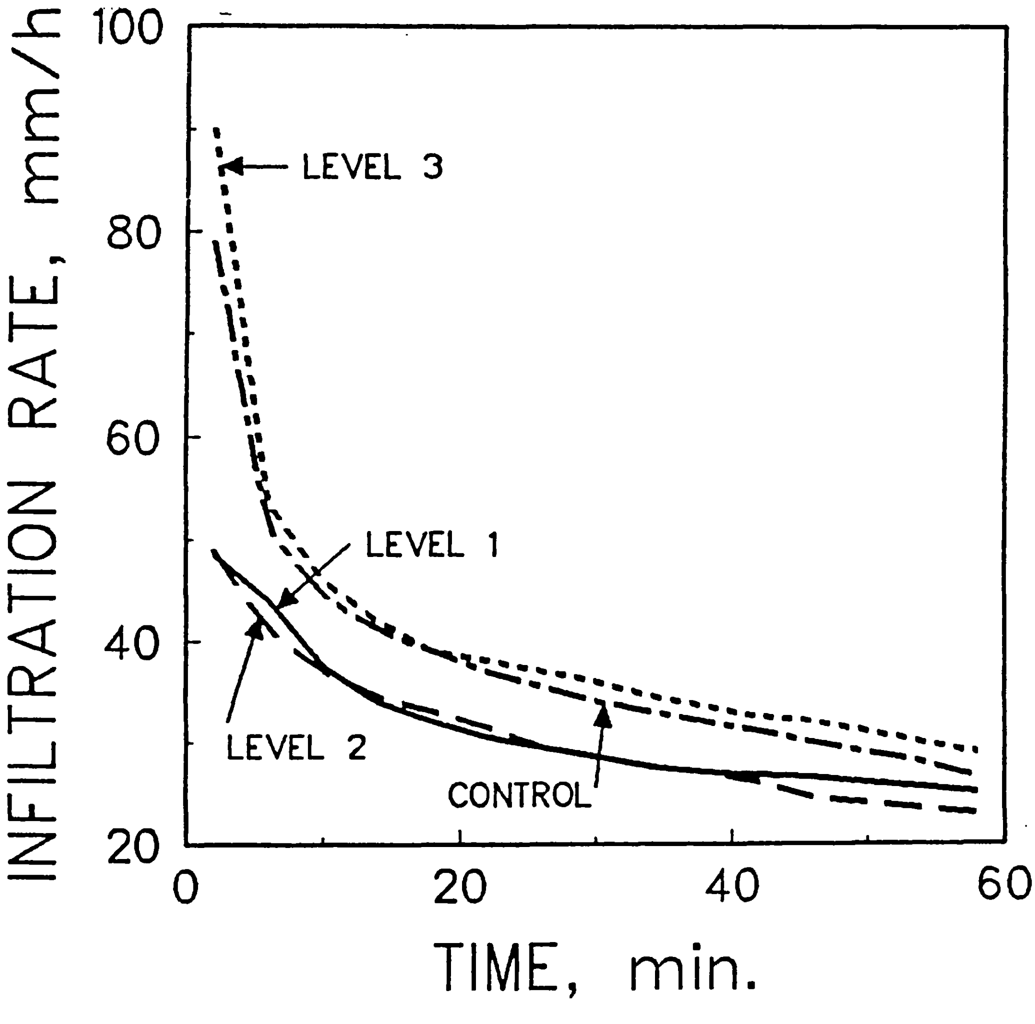


Figure 6.3 Double-ring infiltration rates in October 1991

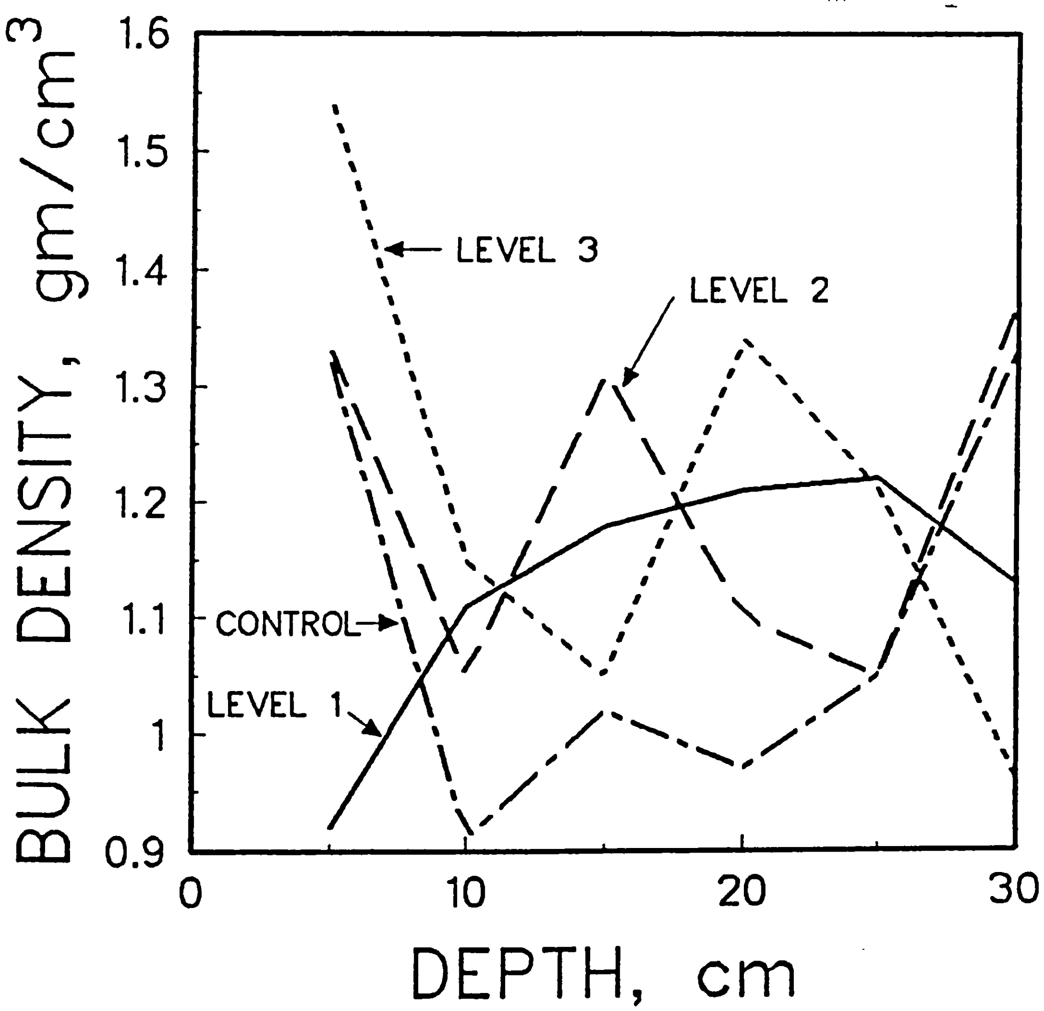


Figure 6.4 Bulk density as a function of compaction treatments

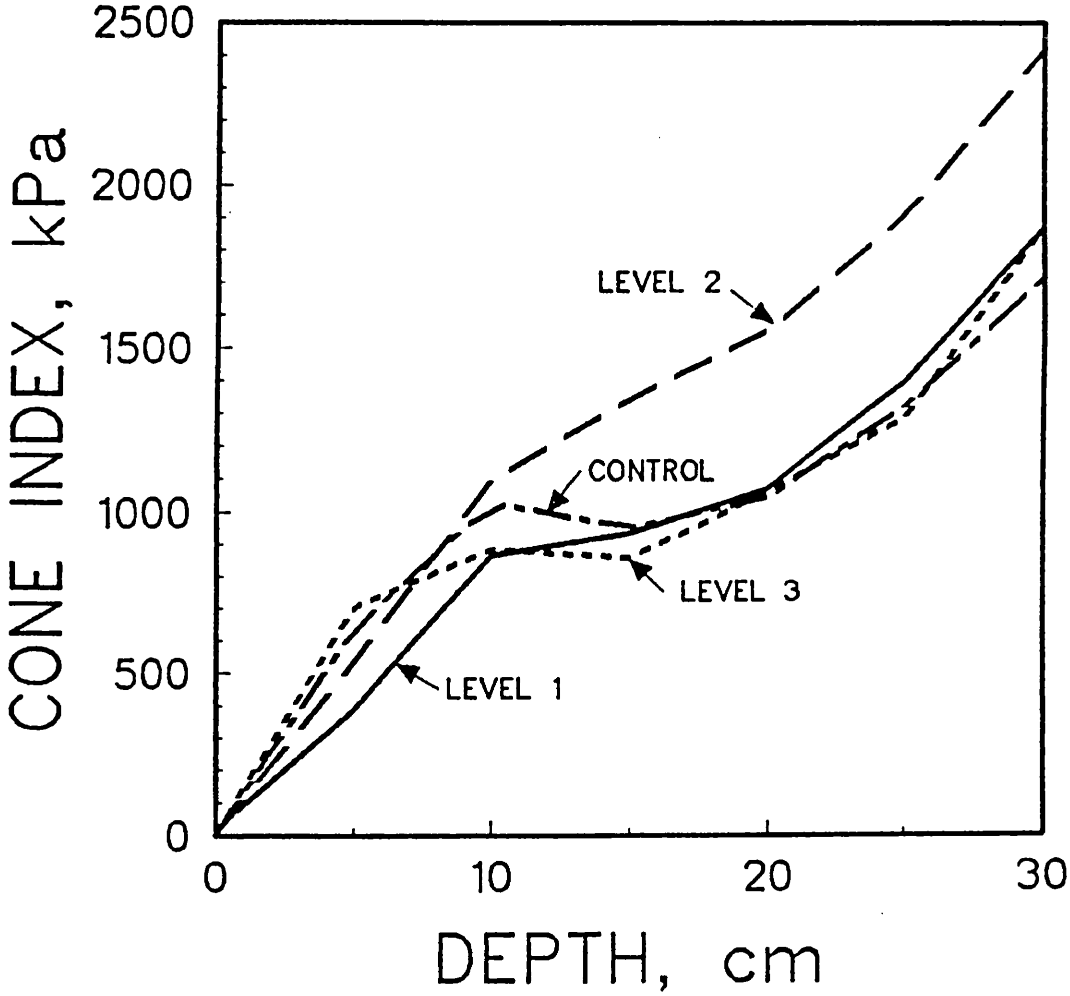


Figure 6.5 Penetrometer readings as a function of compaction treatments

6.7 Measurement of Soil Aggregate Distribution

Traditionally, soil tilth has been measured by the lengthy process of sieving soil samples and from this data the mean area diameter of a sample can be calculated. Chepil and Bisal (1943) built a rotary sieve for determining the size distribution of aggregates. This early approach was based on the modification of the dry sieving procedure, and eliminated a number of weaknesses in the flat sieve method. They claimed that their approach took account of the mechanical stability of the soil and presented a realistic picture of the aggregate size distribution, without destroying its structure.

Chepil and Bisal (1943) examined the process of dry sieving by hand and compared it with the results produced by their equipment: they commented that the hand sieving depended on the operator's performance and the size of the soil sample used, whereas the rotary sieve gave results that that were not greatly influenced by the sample size and were repeatable.

Van Bavel (1949) also developed a method of measuring clod size distribution, otherwise known as aggregate analysis, based on wet sieving. He expressed his results as the mean weight-diameter of a sample and suggested the values could be used in statistical analysis for evaluating the soil structure and differences between treatments by implements. Wet sieving is seldom used today.

By the time Schaller and Stockinger (1953) were working on seed-beds, many methods of assessment had been used and they attempted to compare five of them. They concluded that determining the percentage of aggregates >2mm or >1mm could be a reliable guide and could be obtained more quickly than weight-diameter or geometric mean size of the whole sample. They were concerned to increase the number of samples that could be assessed per man day but they also pointed out the limitations of using any assessment method to predict crop yields. More recently, workers have tended to look at the correlation of assessment and crop establishment, recognising there are many factors other than aggregate size that influence establishment and yield.

In an attempt to standardise the method of representing soil aggregate size distributions, Gardner (1956) examined data from over 200 soils reported in the literature and found that they followed a Logarithmic-Normal distribution. Such distributions, he claims, can be completely characterised by specifying the clod geometric mean diameter and standard deviation. This view was later questioned by Stirk (1958) who drew attention to the need to consider whether the size distribution was symmetrical or not. Stirk suggested that arithmetic mean size (AMS) was a simply determined and useful parameter, but that with any method of expressing aggregate size distribution it is important to recognise its limitations.

Little further work appears to have been done in this area until Cope and Patterson (1989) started to use a photographic technique as a routine method of assessing the effects of implements in a series of seed-bed preparation experiments. This technique was developed to reduce the labour demand associated with sampling and sieving and eventually a set of photographs was produced of different soil surfaces, calibrated against mean area diameter (MAD) determinations arrived at using Van Bavel's method. Photographs of an area of $0.25m^2$ within a rectangular frame were taken with a 35mm single lens reflex camera supported on a tripod at a height of 1.3m above the soil surface. The photographs were developed to produce a print measuring 180mm x 120mm. The authors have recently extended the range of calibrated photographs from the original 7 to 21, covering a range of MADs from 18.7mm to 72.0mm, and these are available at cost from Silsoe Research Institute.

6.8 The Effects of Alternative Methods of Cultivation on Soil Conditions and Plant Growth

Research in dry-land areas has shown that conventional tillage has caused considerable damage to the soil. Repeated tillage operations can induce greater soil erosion and moisture losses. The soil clods once broken into small particles become easy to transport by wind or water, especially with flooding irrigation or when the soil surface is not protected by a residue cover. Consequently, this will cause a constant degradation of the top arable layer of the soil. To alleviate these problems and also to save on labour and energy inputs, conservation tillage practices have become alternatives to conventional tillage. Among factors that affect germination, Tessier (1989) described the following as external factors; water availability, temperature in the seed zone, seeding depth, soil impedance to emergence and crop residues in the vicinity of the seed as major components affecting the soil-seed environment for good establishment.

Many scientists and farmers realised the problem of erosion caused by conventional tillage and started to develop solutions to help stop erosion and moisture loss. The main objectives were to protect the soil from wind erosion by leaving a vegetative cover or minimum tillage with a minimum cost. In the USA Allen and Fenster (1986) identified some early research work on conservation tillage. They cited Noble who developed an undercutting blade tilling the soil without turning it, thus leaving most of the residue on the surface to control wind erosion. Also, they cited Russell and Duley (1977) who showed in their studies in Nebraska that leaving straw on the surface reduced evaporation and thus conserved water, but they encountered the problem of weed control. With the help of Chase, they developed the V-angle sweep blade which proved to be successful in undercutting weed while leaving residue on the surface.

The expansion of these new farming techniques emphasising soil and water conservation produced another challenge, that of seeding through residue. Farmers and scientists started by modifying their existing drills followed by new equipment designs. Disc drills, shovel press drills and air drills were manufactured and by 1960 widely used. Most of the basic designs generated at that time are available on direct drills today.

The interest of developing no-till techniques and management systems has considerably increased. A survey of conservation tillage practices, Conservation Technology Information Centre (CTIC, 1989) showed that farmers have increased the amount of land cultivated by using no-till practices for most of their crops, with the advantage in the conservation of soil and water in semi-arid regions, their impact on the returns in energy savings by reducing the number of tractor passes needed to cultivate the field crop and the possibility to control erosion. A lot of research work has been done in the area of conventional tillage (ploughing or chisel cultivating) followed by direct drilling as a promising farming technique.

Wall *et al* (1991) reviewed the issues and advances of wheat crop management in the warmer areas. Effects of climate, direct effects of higher temperatures and cropping system on soil physical properties and chemical fertility has direct influence on poor root growth and establishment due to compact soil, water logging and soil crusting causing stand reductions. **Figure 6.6** shows interactions between the different effects on wheat production under warmer areas.

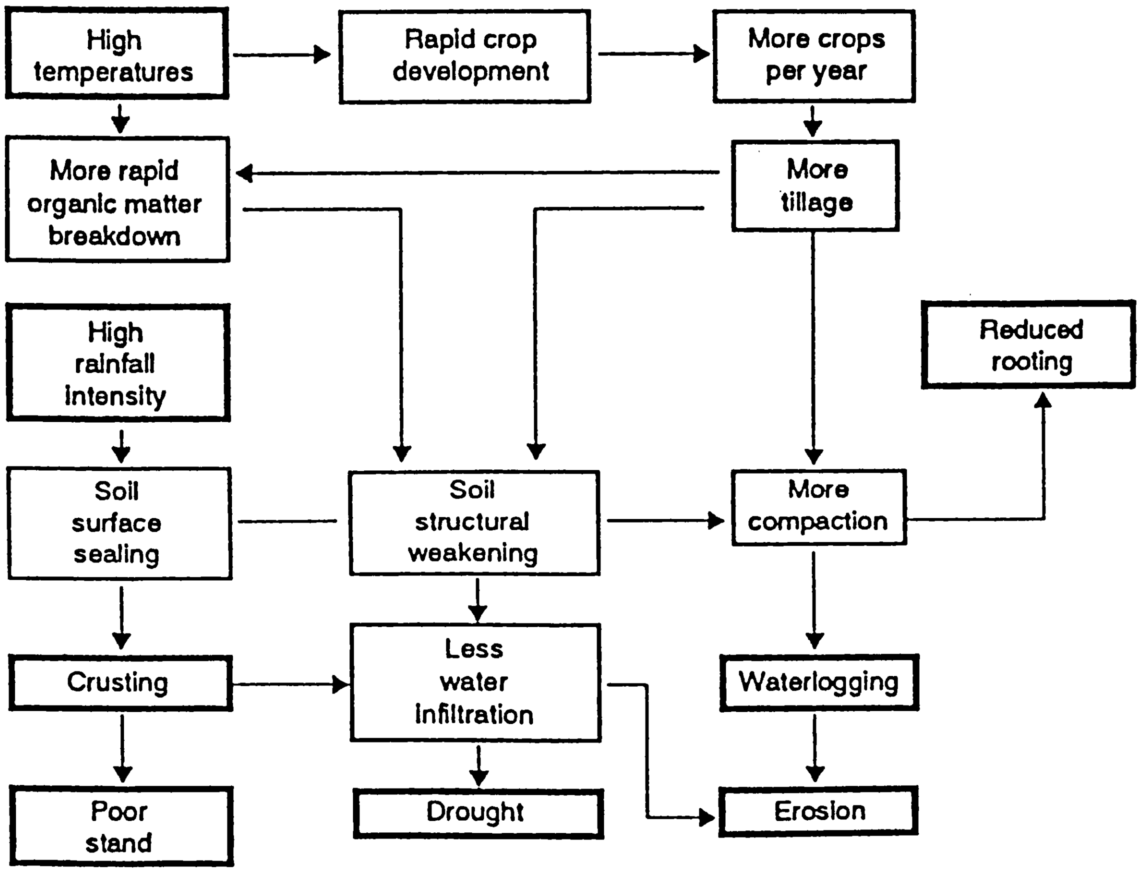


Figure 6.6 Inter-related factors leading to soil degradation, poor crops, and soil erosion in warm environments. Source: Wall *et al* (1991)

Benaouda and Bouaziz (1992) surveyed the fields in the Chauoia region of Morocco, dealing with the technical aspects of bread wheats and establishment, mainly the problems related to germination and emergence, and their effect on the crop production. The results showed that seed losses during crop establishment were mainly due to mechanical obstacles at the soil surface. These obstacles were the result of seed-bed preparation during non-appropriate soil conditions (high soil moisture) and use of the same tools for soil tillage and seed-bed preparation in different situations. The farmers, well aware of these seed losses, use high seeding rates to obtain adequate stands. The yield was very much dependant on the emergence rate which determines the initial stand and the best yield was obtained by an initial stand of 400 plants per m^2. Below or above this limit the yield decreased. They also reported that the use of rollers under dry soil conditions, was a key for the success of the sowing operation. It seems that the Camara levelling device commonly used in the Sudan under dry vertisol conditions to help covering cracks, firm and smooth the soil surface with some levelling and consolidation, serves a similar purpose.

Vieira *et al* (1991) studied tillage practices and soil degradation on a wheat-soya bean rotation in warmer areas of Latin America. The tillage systems used were to disturb the soil layer and to leave the soil highly exposed due to the low level of crop residue on the surface: this involved burning wheat straw followed by harrowing to 15cm depth. The conventional system involved removing some straw, burning its remains followed by disc ploughing to 25cm depth, and combined systems of the above systems. Other tillage systems that do not disturb the soil - at least not significantly - leave the surface totally or partially mulched.

The relationship between soil erosion and tillage systems is shown in **Figure 6.7.** Soil surface pulverization and aggregate stability behaviour in the different tillage systems is shown in **Figure 6.8.** As it can be seen, the conventional system shows lower aggregate stability compared to chiselling and direct drilling. It seems that in tropical, non-traditional areas for wheat, where rainfall and temperature are high, farmers' use of chiselling has increased slightly in recent years, mainly due to its high output efficiency (ha/day), also they are aware of the problems caused by disc harrowing (smearing) over the long term. Farmer acceptance has been somewhat restricted because weed control has only been fair and the power requirements required for chiselling are high (Hoogmoed and Derpsch, 1985).

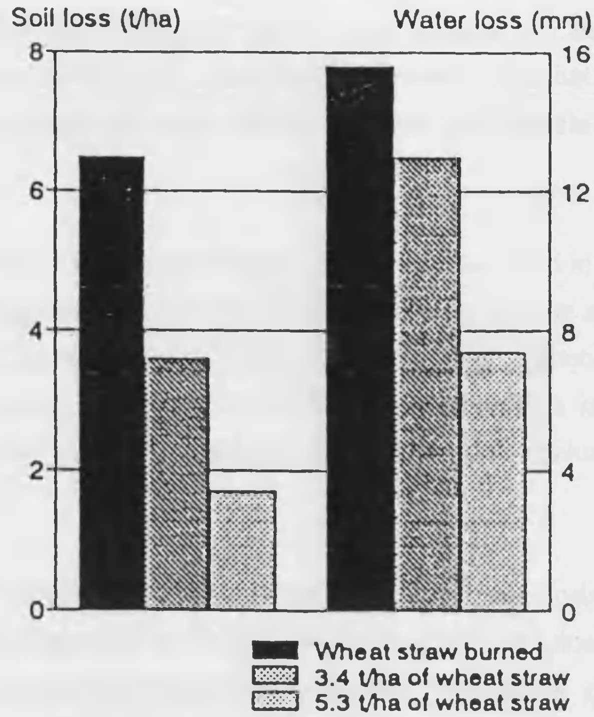


Figure 6.7 Soil erosion as effected by different management and amounts of wheat crop residues. Source: Vieira and Mondardo (1981).

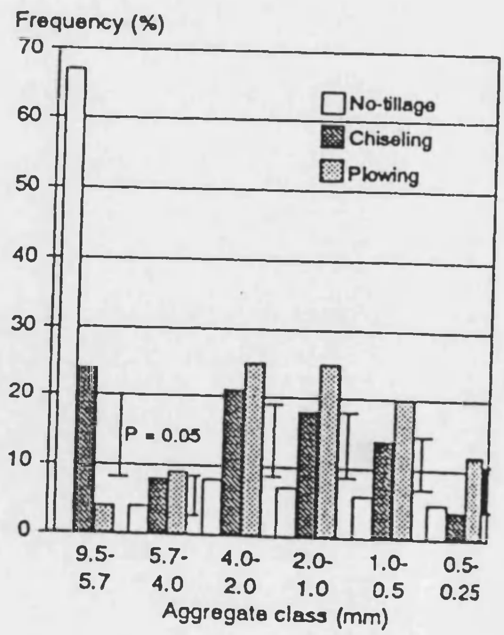


Figure 6.8 The distribution of soil aggregate classes in the topsoil (0-10cm) resulting from different soil tillage methods in an Oxisol. Source:Sidiras *et al* (1992).

The water infiltration rates under the three tillage systems are shown in **Figure 6.9.** Infiltration rate under no-tillage is substantially greater than that using conventional tillage. With chisel ploughing, water infiltration has intermediate values between the other two systems.

Figure 6.10 shows the average percentage of leaf area infected at each tillage system and different crop rotation. There were no differences in disease severity between the cropping sequences. However, irrespective of the cropping sequence, tan spot severity was always substantially higher in the no tillage system. This is possibly since the disease is favoured by higher temperatures, the presence of previous crop residues and moisture.

Willcocks and Twomlow (1993) reviewed tillage methods, soil and water conservation in Southern Africa, where the risk of soil erosion is often high and current yields are low in semi-arid regions. The objectives of tillage work are generally to prepare seed-bed for germination of planted seed, a soil surface which resists erosion, to control pests, weeds and previous crop residues and to loosen the soil for air, water and root penetration. Tillage usually constitutes the highest energy input for cropping and involves scarce resources - poor farmers need farming systems that keep mechanical manipulation of the soil to a minimum and also conserve scarce water and soil resources.

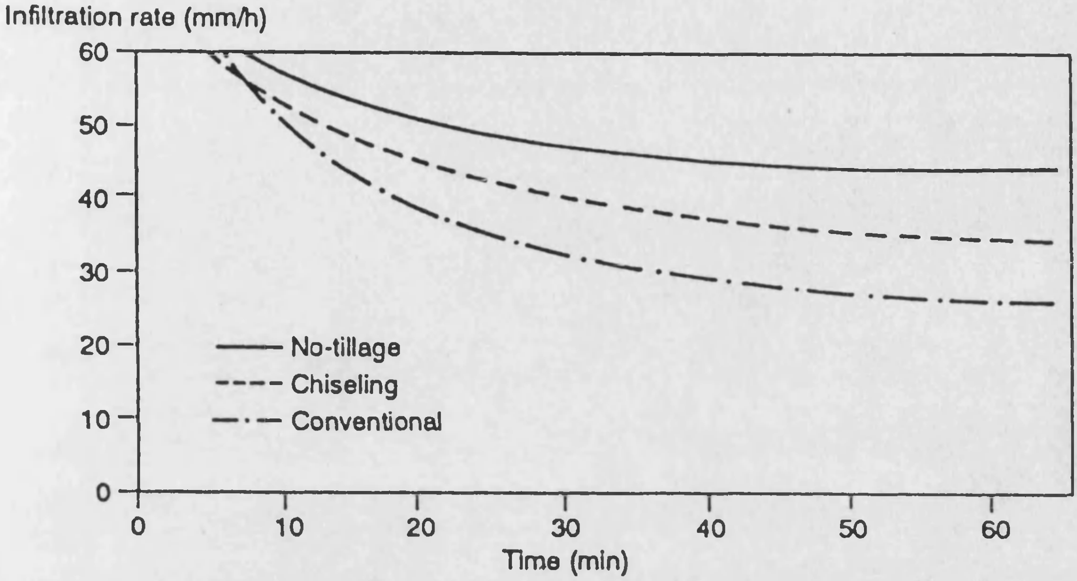


Figure 6.9 Infiltration rates in oxisols during the soyabean cycle under different tillage systems at a rainfall intensity of 60mm/h. Source: Derpsch *et al* (1986).

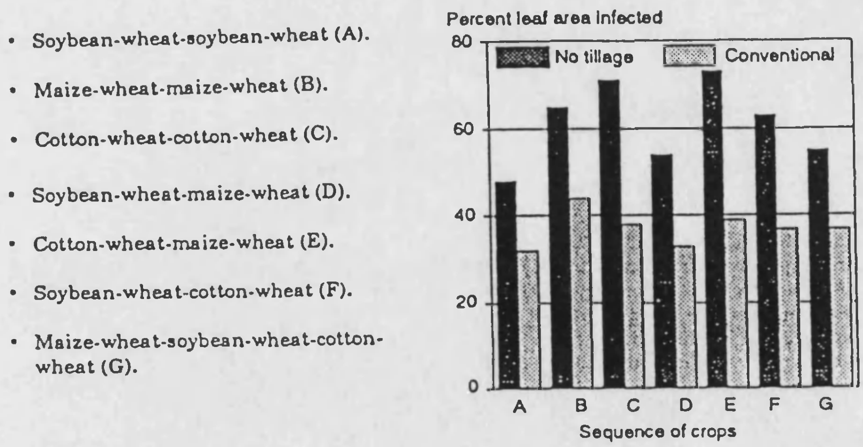


Figure 6.10 Effect of tillage practices on the severity of tan spot in wheat cultivar Mitacore. Disease assessment was done 92 days after sowing. Londrina, 1983.

6.9 'No-Till' Drilling

The major functional performance requirements for no-till grain-drills are good residue cutting, uniform soil penetration, good depth control and uniform seed placement and coverage (Smith and Klocke, 1985). The ability of the drill to achieve these functions will ensure a favourable environment for acceptable germination and emergence. Even if success of no-till seeding depends largely on the performances of the coulter, the opener and the press wheel, there are other factors that should be taken into consideration to achieve a uniform distribution of the previous crop residue and a good weed control programme are necessary for the success of seeding in no-till conditions (Smith, 1986).

Good crop establishment does not depend only on the seeder performance but on the good integration of the crop production management system with the seeder (Smith, 1986). Marrison et al (1988) established guidelines to help users to select the best seeder and components for their specific field conditions. Bahri (1992) evaluated different combinations of openers and press wheels for no-till grain drills when seeding wheat in the semi-arid regions of Sidi El Aydi and Jemaai Riah. The study involved combinations of three furrow openers with two press wheel types on the basis of creating a suitable soil-seed environment for a good establishment of wheat in no-till conditions. The study included soil disturbance, bulk density, soil moisture, seeding depth and plant stand. Results obtained showed that the hoe opener created maximum soil disturbance and opened a larger and deeper furrow, consequently soil bulk density in the furrow was lowest. The double disc opener did not leave much impression on the soil surface which also reflects in high bulk density values and that was clearly observed at both locations in Morocco.

In general, the double rib press wheel retained more moisture compared to the narrow rounded press wheel because it compacted a larger furrow width. All the furrow openers and press wheels placed seeds at 5-6cm at Sidi El Ayid, however, none of the openers reached a desired seeding depth of 5-6cm at Jemaai Riah because of a relatively hard and dry soil condition. In crop residue tests at both locations in Morocco the hoe opener placed seed deeper compared to other openers, but the double disc opener maintained the most uniform seeding depth. Press wheel type generally had no significant effect on seeding depth. The study also concluded that in relatively moist and loose soils the double disc opener was most suitable for use on a no-till grain drill, also it is important to have a coulter ahead of the opener to cut through residue to avoid blocking of furrow openers.

Golabi *et al* (1988) studied the effect of long-term no-till on soil physical properties and reported that more water was stored under the no-till treatment compared to conventional tillage. Also they found that no-till helped in the development of macropores in the soil profile and thus improved water infiltration and storage.

In a report published by CTIC (1989) no-till is reported to help in creating a favourable environment for earthworms. The increases earthworm-activity enhance water and gas flow, root penetration and residue decomposition. It seems that the response of no-till practices on grain yield has been relatively difficult to monitor because of the effect of other factors such as weed control, suitability of sowing and fertiliser application equipment, disease control etc., particularly under hot irrigated conditions.

Tompkins (1985) reported that yield reduction in cases of no-till has been associated with poor weed control and/or poor crop establishment. Jasa and Dickey (1990) concluded, from a five year study in Nebraska, USA, that no-till gave best yields among all treatments tested for both soya beans and sorghum. Richard *et al* (1988) reported from 11 years of data that no-till gave good wheat yields from a wheat fallow rotation and concluded that the no-till technique induced greater stability in wheat yields over that period, however, it seems that the situation is difficult under semi-arid conditions where flooding irrigation is used and where ambient temperatures are high, which is a suitable environment for weed infestation.

Grain drills for no-till have several soil-engaging components and have to operate un-tilled, compact and residue covered soils, thus they must be heavily constructed to provide penetration in these conditions (Tompkins, 1985).

No-till seeding equipment should be designed to achieve the task as outlined by Morrison and Abrams (1978). The intensive research by different institutions in the field of conservation tillage and no-till has resulted in the development of a wide variety of equipment. The most interesting implement in no-till farming is the grain-drill and grain-drills with many different designs exist. H. Allen (1981) published a book on direct drilling and the development of alternative cultivations. He reviewed some early trials and long term field experiments undertaken since 1961. Smith and Klocke (1985) indicated that success of no-till seeding depends largely on the performance of coulter, furrow opener and press wheel.

6.9.1 Coulter

The coulter is required to cut through the residue and prepare the path for the furrow opener for proper seed placement. Krall *et al* (1978) compared several coulter openers - press wheel combinations and found that a coulter of 40cm diameter gave the best results, while there was no significant difference between smooth, ripple edged and wide fluted coulters in the cutting of residue, except the latter caused more soil disturbance.

Erbach and Choi (1983) found that smooth coulters required less force to cut through heavy residue and to penetrate a dry soil than wider ripple and fluted coulters. Kushwaha *et al* (1986), reported that performances of a coulter in cutting straw were influenced by the soil strength. Further study showed that a 46cm diameter smooth disc coulter was most efficient in cutting through straw at different densities and at different depths of penetration.

6.9.2 Furrow Opener

The expected functional requirement of a furrow opener for direct drilling includes the ability to penetrate in dry conditions with a minimum of soil disturbance, open a narrow furrow while moving the residue cut by the coulter to both sides, place seeds at the bottom of the furrow where moisture is available, and maintain a uniform seeding depth.

Shaaf *et al* (1979) found that the hoe opener caused the greatest amount of soil disturbance, required a higher draught force and a lower vertical force compared to the disc opener. Further studies by Shaaf *et al* (1981) evaluated different types of furrow openers and found that narrow slot type hoe opener and narrow double disc opener are most suitable for direct drilling. Payton *et al* (1985) mentioned that in no-till seeding of wheat the hoe opener gave significantly higher grain yield compared to the double disc opener. The performance of an opener can vary depending upon soil type and physical conditions, eg. when operating in heavy stubble residue an opener that clears the seed-row from residue should be used. Smith (1986) and Klocke (1979) reported that hoe openers perform well under dry hard conditions while disc openers are more appropriate when seeding in soft and moist soils. This concurs with the results obtained by Bahri (1992) under semi-arid areas of Morocco that the hoe opener is better suited for hard and dry soil conditions at sowing time in Morocco because of better penetration, it also created a great amount of soil disturbance which may be an advantage for creating a better soil-seed contact.

6.9.3 Press Wheel

The main purpose of having press wheels is to cover the seed with soil and improve the soil-seed contact. On most grain drills, press wheels are also equipped with depth control mechanism. Shaaf *et al* (1981) recommended that in no-till conditions, the press wheel width should be equal to or less than the width of the furrow created by the opener, otherwise the press wheel will ride on the furrow wall causing insufficient compaction for a good soil-seed contact. Further studies by Morrison *et al* (1988) found that the seed furrow closure and firming must be compatible with the amount of loosened soil. Single rib and narrow rounded press wheels exert a lot of pressure on the seed to firm it into the soil around the seed. However, under semi-arid conditions of Morocco, Bahri (1992) reported that the press wheel type had no significant effect observed on different parameters, but the double rib press wheel may be preferred because it did a better job of seed covering and soil compression which reflected in more soil moisture in seed rows.

6.10 Current Situation of Tillage Research in Morocco

Conservation tillage and no-till are relatively new concepts in Morocco, except for the experiment conducted by Bouzza (1990), no other major research effort has been reported (Bahri, 1992). Bouzza (1990) carried out a four year-study in semi-arid area of Morocco at Sidi El Aydi near Settat comparing no-till technique, minimum tillage (chiselling) and conventional tillage (disc plough followed by twice disc harrow). He found that no-till results showed better yield over the other treatments in dry and wet years, and early planting was very important in these regions so that the crop benefited from total rainfall during the season. The yield advantage from no-till and minimum till were attributed to soil moisture and soil physical conditions that allowed early sowing. In a continuous wheat system and in a dry year, no-till yielded 200kg/ha more grain than minimum tillage and 250kg/ha more than conventional tillage. The differences in yield were much higher in a relatively wet year. No-till treatment produced 247kg/ha more grain than minimum tillage and 1135kg/ha more than conventional tillage. In addition, conventional tillage produced a rough and dry surface unsuitable for sowing wheat until after the first good rains. Thus no-till and minimum tillage practices are promising techniques for cereal production in Morocco. Also, he mentioned two major problems in need of more investigation: these are the high cost of chemical for weed control and the availability of suitable equipment for sowing and fertiliser application and both may prevent the adoption of no-till and minimum tillage practices in Morocco.

Many experiments were conducted at different locations in Morocco on weed control by Bansal *et al* (1990) who concluded that one post-emergence herbicide application can satisfactorily control weeds for wheat production which would cut the costs of chemicals but still the cost of direct drilling equipment is expensive compared to the conventional seed drill. However, economically, no-till practice saves the farmer substantial production costs and makes the wheat cultivation more profitable. In Pakistan, ploughing and planting costs for wheat after rice were estimated between US$ 50-60 per hectare which is almost 20% of the cost of production (Majid *et al*, 1988). Similarly, Byerlee *et al* (1984) reported that in India, zero tillage gave significant saving in expenditure and energy required for sowing wheat compared to traditional methods.

Recent tillage research under semi-arid conditions at Gharb in Morocco is concentrated on sugar beet (*Beta vulgaris* L.). Salouani (1993) studied the effect of different tillage systems on the establishment of sugar beet. Results showed that disc ploughing followed by powered rotary cultivation made a favourable seed-bed for germination and emergence of sugar beet, with a lower penetration resistance of soil. However, the best emergence rate was found with the Dutzi combined machine which showed good effects on soil physical properties especially bulk density and total porosity.

Another experiment was carried out by Hiba (1993) to study the effects of different tillage systems on production and quality of sugar beet in the Gharb. Results obtained showed that disc ploughing to 20cm depth followed by rotary cultivation achieved a good seed-bed with 5% emergence rate higher than disc ploughing followed by a heavy tine cultivator. However, the Dutzi combined machine gave a good response to growth of roots and shoots and an average increase of 8.94t/ha in yield as well as increased sugar yield.

More field experiments were carried out by Siada (1993) studying the effects of different tillage systems on sugar beet under semi arid conditions of the Gharb. Results obtained showed that the Dutzi multi-function machine with the share removed, on the weak soil of Gharb achieved a good seed-bed with a better germination, 9% higher emergence rate compared with a disc harrow. Also the results showed that the roots with a weight lower than 1kg were more abundant, nevertheless, the importance of the presence of beets with a weight higher than 2kg allowed a rapid increase of the quantitative yield. The presence of 1% of beets weighing 2kg allowed a yield increase of 2t/ha. However, the beet quality was lower (less sugar). Sugar concentration ranges from 17% to 18% when the beet weight ranges from 1 to 2kg.

6.11 Direct Drilling and Residue Management and Their Influences on Weeds, Diseases and Pests

In Australia, Bacon and Cooper (1985) demonstrated over 4 years that direct drilling techniques with the rice stubble retained on the surface or burned gave up to double the growth of plants where the stubble was incorporated or burned and then cultivated. It seems that burning the stubble did create a problem in some years and because it exposed the soil and heavy rain caused crusting, which inhibited water penetration and subjected the plants to severe drought stress later.

A further step in 1985 was taken as a practical way to broadcast wheat seed in the standing rice crop. Majid *et al* (1988) cite Saunders, (Pers Comm.) that in Bangladesh an area of 810ha of wheat was planted into rice. The mean overlap was about two weeks and the highest yield was 2.8t/ha, the mean yield of 1.5t/ha was 500kg/ha less than the national average and that due to the hot climate in Bangladesh and the seed being broadcast on the soil surface the wheat did not develop a good root system when temperatures were high. Majid *et al* (1988) studied the potential use of conventional and minimum tillage in wheat after rice in Pakistan, traditional land preparation for wheat after rice consists of 6 to 8 cultivations with the spring tined cultivator followed by levelling with a heavy wooden plank, usually after every two ploughings, the land is left for a few days to allow residue decomposition before the next ploughing, and planted after a satisfactory tilth has been made, although in many cases the seed-bed is not suitable for wheat establishment. Some farmers use rotavators to get a better seed-bed but with higher costs.

A comparison was made between traditional seed-bed systems and a system of planting directly into the rice stubble. The results obtained showed that grain yield and biomass production were similar. Spikes/m^2 were equal or even better with direct drilling, whereas other yield components showed a compensatory effect. Direct drilling improved plant establishment (**Table 6.7**) and that is possibly because of more uniform placement of seeds in the soil.

Dhinam and Sharma (1986) compared five different tillage systems on yield of wheat after rice under heavy soils for two years. The best results occurred with six tillage operations with spring tined cultivator and irrigation before field preparation, but these results were not significantly different from other treatments with less cultivation. Energy requirements and expenditures on sowing operations were maximum for the above treatment (19.6 kWh/ha and 222 Indian rupees/ha) and the lowest in direct drilling (18.2 kWh/ha and 80 rupees/ha), also it reduced time and power invested.

The use of a powered rotary hoe in combination with deep ploughing should produce a good seebed in reduced time. However, unless the plough pan is reformed, water use in the next rice crop will be significantly increased.

Dhinam and Sharma (1986) compared zero tillage with traditional methods of tillage for wheat after rice under heavy textured soils. They found that preparation of a suitable seed-bed for wheat after rice is almost impossible and very costly. **Table 6.8** showed that part of the benefit of direct drilling was due to being able to plant 5 days earlier. Hobbs (1985) used 4 years of planting data from Pakistan, he found the late planting of wheat is the major reason for low wheat yields in this cropping pattern.

Majid *et al* (1988) reported on the late planting of wheat after rice. The variety of Basmati rice does not mature until after mid-November and many farmers do not harvest it until December, also many farmers put priority on drying and threshing the rice crop, one of the major cash crops, before starting land preparation for wheat. Estimated wheat yield losses of 35-40kg/ha per day were found when wheat was planted after November 20th (Randhawa *et al*, 1981).

Table 6.7 Effect of tillage operations on number of plants emerged per m^2, number of weeds per m^2, and percentage of tillers infested by stem borer (1985-86).

	Emerged plants/m^2	Number of weeds/m^2	Tillers infested with stem borer (%)
Direct drilling	114	43	12.0
Conventional planting	96	66	3.1
Significance	*	*	*

Source: Majid *et al* (1988)

Table 6.8 Effect of zero tillage on the yield of the wheat variety Sonaliki, 1982-83

	Grain yield	Grains/ spike	1000- grain wt wt	Spikes/m^2
Zero tillage	4.17	32.7	54.2	314
Conventional	3.68	30.4	50.8	254

Source: Dhinam and Sharma (1986)

Meelu *et al* (1979) and Dear et al (1979) found that the resulting poor stands (plant/m^2) are a factor in poor wheat yields after rice under heavy soils. Another factor is the low N availability resulting from extensive removal of mineralised nitrogen by rice and microbial immobilization of N applied to the following wheat crop, increased soil bulk density and reduced soil stability after flooding and puddling could also be important.

Some fertiliser studies were carried out by Bacon and Cooper (1985) on methods of application using data from Australia and Pakistan. Results showed that fertiliser can conveniently be broadcast after emergence without loss in efficiency, even in Pakistan, phosphate can be broadcast at the first irrigation with no loss in yield. This method is difficult to use under Moroccan conditions due to the increasing temperature after sowing time, so most farmers broadcast phosphate during seed-bed preparation to allow time for the nutrients to be released in the soil.

Majid *et al* (1988) also studied some other tillage methods for wheat after rice. The study involved traditional bullock plough and spring-tined cultivator, which are often used in India and Pakistan, but they are not ideal implements for seed-bed preparation for wheat after rice. In 1984, they used a mouldboard plough followed by a spring-tined cultivator which was compared with conventional tillage and direct drilling. There were no significant differences between these tillage implements. However, in the area where the experiment was done, subsoil sodium and salinity were brought to the surface by the mouldboard plough and affected wheat growth although the plough reduced the problem of rice stubble residues satisfactorily. It seems that the mouldboard plough is not entirely suitable for use in wheat seed-bed preparation under Moroccan conditions due to the shallow layer of fertile soil.

Panel members at the meeting of Wheat for Non-Traditional Warm Areas (1991) reported that stem borers in the rice-wheat systems of Asia provide a good example of where direct drilling was adopted and insect problems appeared, because rice straw if not burned, decomposes slowly enough to allow sustainability of stem borer carry over, however, burning the stubble can increase the risk of soil erosion.

6.12 Equipment and Development

Sims *et al* (1994) designed the modified tied-ridger to suit many semi-arid regions of the world where small farmers have no access to irrigation water. This is the situation in Aguascalientes State, Mexico where the basic development work was carried out. The manually operated tying release mechanism is simple, being a spring loaded catch which is released by a vertical pull on a piece of string (**Figure 6.11**).

Jenane *et al* (1992) designed and built a powered flail tool for residue manipulation in conservation-tillage planting (**Figures 6.12** and **6.13**). Field testing showed that the powered flail is able to cut through a high density of residue, approximately 6700kg/h, with no difficulty. The input power required to rotate the flail ranged from 0.2 to 5.2kW, depending on soil conditions and the level of residue. Results of emergence percentage and planting depth showed no significant differences between using the rolling coulter or the powered flail tool.

Choudhary and Aban (1985) mentioned that after some success of zero tillage under Pakistan conditions, some joint research work between Pakistan and New Zealand carried out to develop a suitable drill to plant wheat after rice. A single row drill is shown in **Figure 6.14**. The prototype gave excellent results and the opener create in-groove micro-environments that facilitate proliferation of plant shoot and roots. It allows the surface soil and residue to remain intact, the seed metering assembly uses a horizontally mounted circular foam pad which allows seeds to be delivered vertically downward through a throat type opening moulded as an integral part of the hopper base.

This technique allows a range of seed species to be metered without damage and this is important for farmers who grow several crops on their land and would ensure uniform and proper placement of seed in any soil condition. It seems to some extent that this is not possible to combine direct drilling and fertilising as one field operation under hot irrigated environments, due to the high losses of N caused by the high ambient temperatures. Flooding irrigation is sometimes delayed due to the low flow of water in sub-main channels which can cause harm to the seeds. Most farmers apply fertilisers during seed-bed preparation in ample time for the nutrients to be released before seeding. This is particularly important with phosphate.

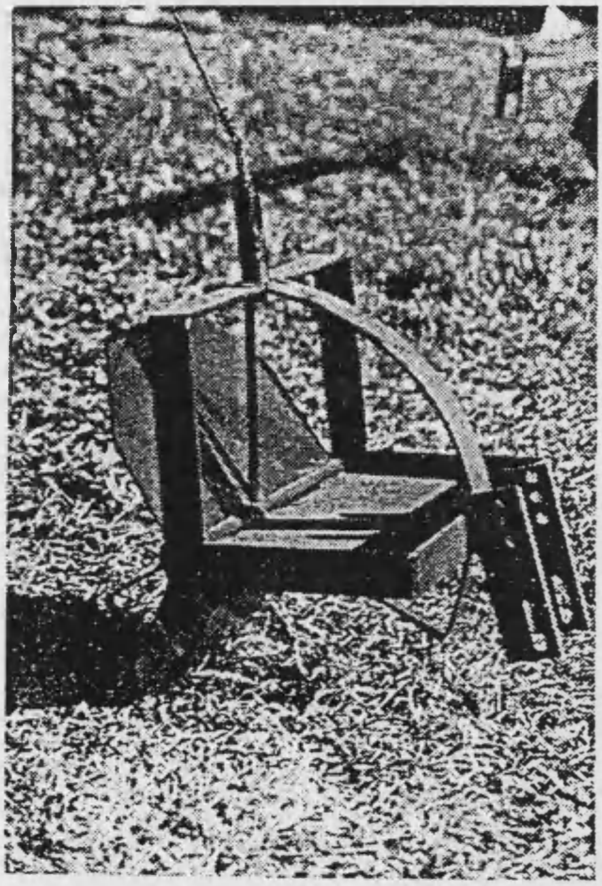


Figure 6.11 The manually operated tying system of the modified tied-ridger.

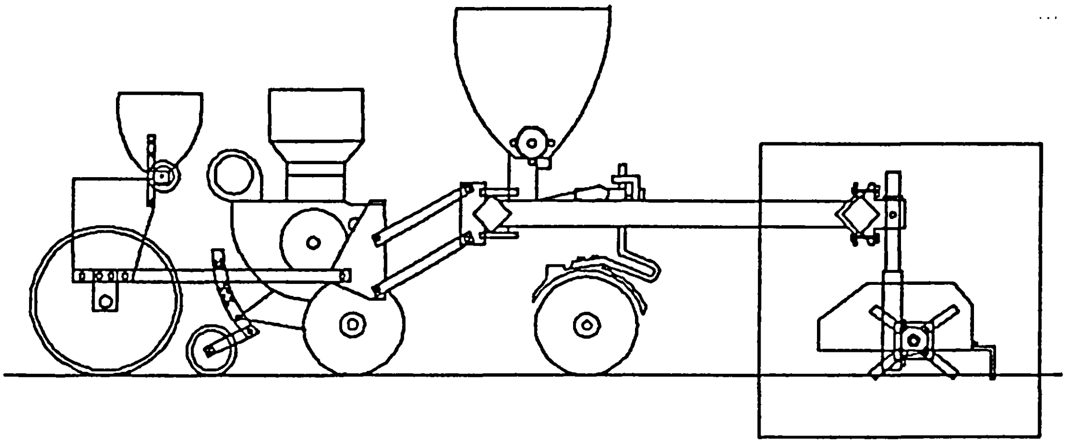


Figure 6.12 Design concept of the powered flail tool

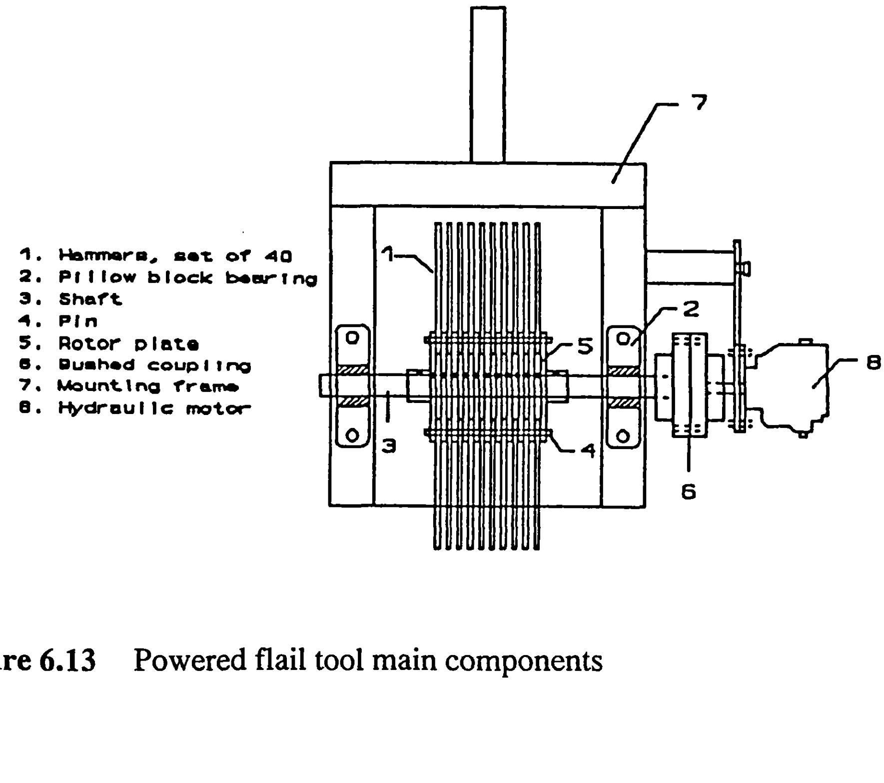


Figure 6.13 Powered flail tool main components

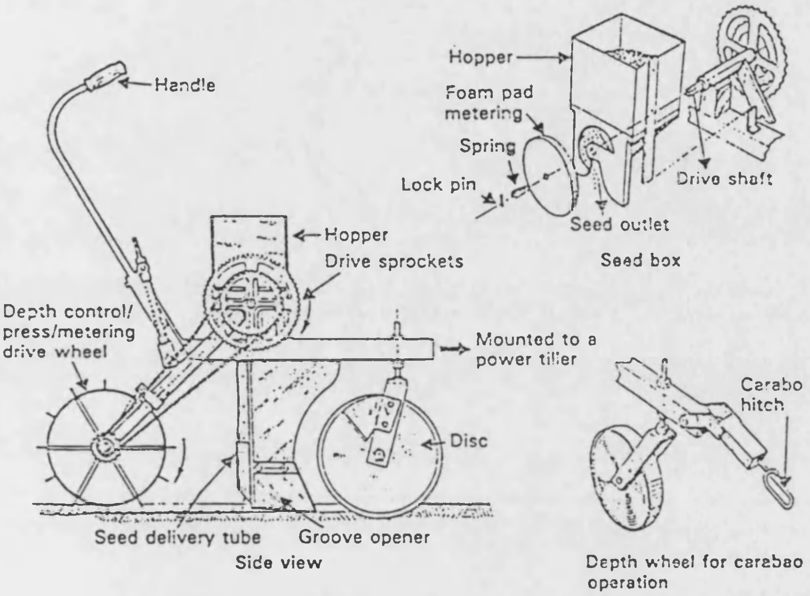


Figure 6.14 Side view, seed box, and depth wheel of inverted-T multi-crop seeder

Knechtges (1992) considered the particular requirements of developing countries and used modern devices of measurement in field testing of semi arid regions of Morocco, within the scope of a project financed by the European Community, with flexible use and possible accuracy of measurements. The three principal methods of measuring the forces between the tractor and the attached tool are shown in **Figure 6.15.** The force measuring devices with a separate frame, which can be located between the tractor and the tool are widely spread. The important advantage of this method is that basically all the forces and movements between the two can be measured for a wide spectrum of tools.

The equipment shown in **Figure 6.16** is designed only for the recording of tractive power from the three floating position driven tools, attached to an autotronic tractor. In the case of an electronically controlled three-point hitch it is easy to replace the loadpin by a true to form sensor of high accuracy. These are only measuring the horizontal forces in the lower link, which are relevant to the drawbar power. The top link is additionally equipped with a link cell and an inclinometer and forces can be measured without changing the geometry of connection in the controlling position of the power lift.

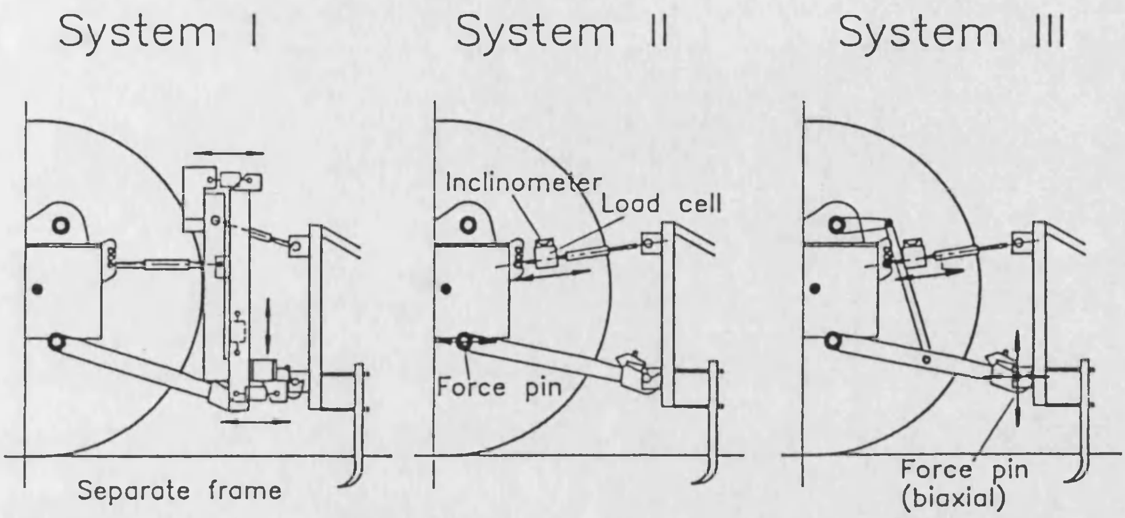


Figure 6.15 Methods of measuring the forces between the tractor and the implement

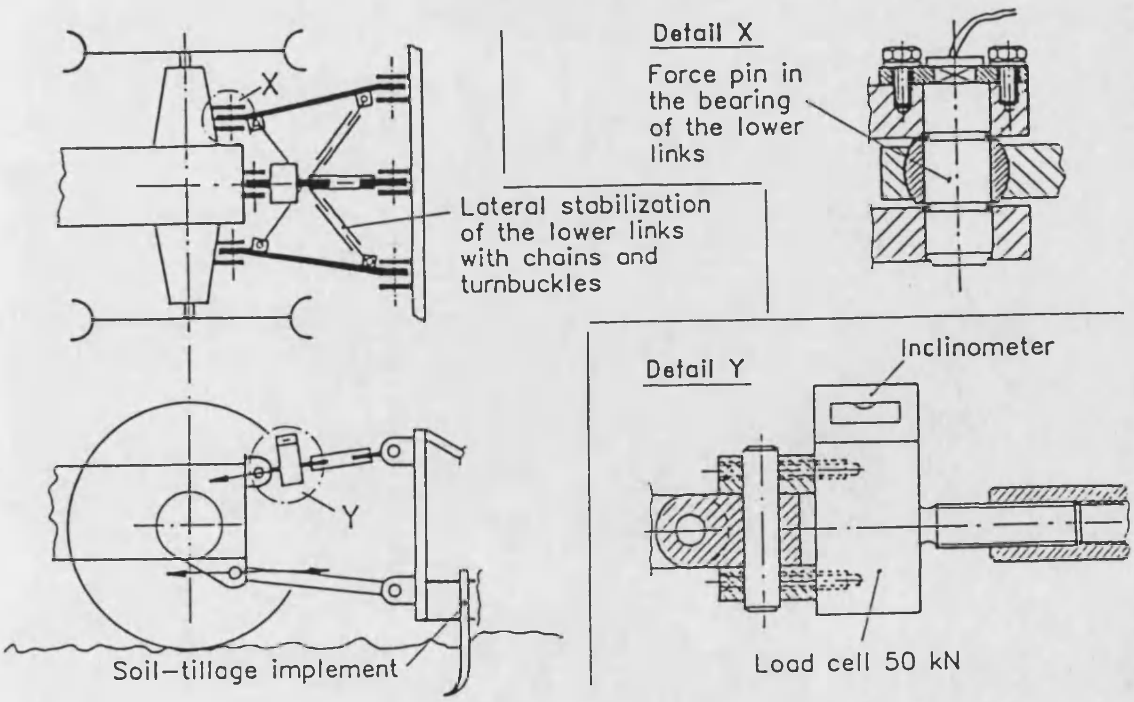


Figure 6.16 Reduced equipment to measure the forces between the tractor and the implement.

6.13 The Cost of Operating Farm Machinery

Johnson (1990) at the Overseas Department, AFRC Engineering outlined the principles of estimating the costing of farm machinery for developing countries. No fundamental change has taken place in the parameters since that time. All the work that has been published since then on tractor costs indicated that it would require a considerable amount of detailed data to operate, most of which is not available. This is a similar situation to Morocco. However, the likely fixed costs in the UK were calculated to provide a basis for comparison.

Estimation of Operating Costs (UK)

Wheeled tractor 92hp (68kW) Purchase price = £ 23,000

Annual hours worked 1000h Depreciation 20%

	£	£/h
Depreciation	3,093	
Interest on capital	1,237	
Road fund Licence	35	
Insurance @ £12/£1000	276	
Annual Fixed Costs	4,641	4,64

Spares and Repairs (% of MRRP)	7%

	£/h
Fuel: 10.08 litres/hr @ 13.5 p/litre	1.36
Spare and Repairs	1.61
Operating Costs	2.97
+ Fixed Costs `	4.64
+ Labour	6.73
Total operating tractor costs	14.34

Depreciation: Calculated on a reducing balance basis over 5 years.Interest: 8% on the outstanding balance over 5 years.

Spares and Repairs: expressed as a percentage of the £23,000 price. (MRRP-Manufacturers Recommended Retail Price)Labour: This is the cost of employment not the rate of pay.

(Agro. Business Consultants Ltd, 1993)

6.14 Situation in Morocco

According to Dycder and Bourarach (1992), the mechanization of soil tillage in the semi-arid regions of Morocco "is not yet on a satisfactory level".

The most commonly used implements are disc ploughs and disc harrows, especially on the heavy soils. They do not work effectively, often three to five passes being necessary to produce a fine structured seed-bed at excessive cost. Also, conventional tillage makes soil vulnerable to erosion by wind and water. The more immediate unfavourable effects of repeated tillage are from moisture loss through excessive evaporation and soil compaction caused by tractor traffic, meaning poor crop establishment and sub-soiling probably being required every two to three years (Ryan *et al*, 1992).

Dycder and Bourarach (1992) concluded that "for these reasons, there is a need for establishing new types of tillage systems which correspond to the pretensions of cultivation in semi-arid regions in quality of work as well as in efficiency".

Traditionally in Morocco, hand-broadcasting seeds of wheat and barley is common, followed by one pass of an offset disc harrow for seed covering. The main disadvantage of this is that it requires a high input of labour. There is also a need for very high seeding rates of 175-350kg/ha to compensate for the loss of seed placed too deep to emerge or left on the soil surface and eaten by birds (Moore *et al*, 1993).

The results at four locations in the semi-arid regions of Morocco in season 1990-1991 (before the drought years began) showed that sowing wheat using a conventional seed drill at a seed rate of 120kg/ha produced an average increase of 7% (152kg/ha) in grain yield compared with the farmer's usual practice of broadcasting at 180kg/ha.

Generally, the actual yields varied considerably from one location to another because farmers chose different wheat varieties; yields were also influenced by crop rotation. The higher yields were recorded where the crop in the previous year was a legume instead of cereal (Bansal *et al*, 1994).

Direct drilling is a relatively new concept in Morocco and so far has only been used in experimental situations. This is due to the cost of the machine, the high power requirement, problems with weeds and the limited availability of equipment (Bahri and Bansal, 1992).

6.15 Objectives of the Project

1) To further investigate the effects of further reduction of the reduced tillage system with two seed rates and sowing methods on wheat establishment, crop development and grain yield under the semi-arid conditions of Morocco.

2) To investigate the effects of drilling and broadcasting with higher and lower seed rate levels than normally used by the farmers and determine to what extent the cost of wheat establishment can be reduced without excessive loss of plant establishment and yield under hot irrigated vertisol environments.

3) To compare the direct drilling technique, conventional tillage and reduced tillage systems and their different effects on seed-bed preparation, crop emergence, growth and yield.

4) To determine the machine performance for different implements using an Autotronic tractor equipped with data logger and central processing unit to collect and record the required data which will be used to assess the optimum operation cost for each operation in seed-bed preparation under Moroccan heavy cracky soil conditions.

7.0 MATERIAL AND METHODS

7.1 Study Area and Layout of the Land

The site of the experiments were located on Sidi Allal Tazi Agricultural Research Station Farm (INRA) at Sidi Allal Tazi, 90km North from Rabat, Morocco during the 1994/95 season. Experiments were carried out on a field of approximately 1.5 hectares area, fallow for the last three years, highly infested with weeds, shown in **Plate 7.1.** (Latitude 6°21'N, Longitude 34°31'E)

The soil characteristics on the site were typical of a relatively large area of Morocco's Semi-arid Zone being a heavy clay soil classified as a vertisol Vertic Calcixeroll over 50% clay, cracky and rich in K (Hilali, H., pers. comm.). Shown in **Plate 7.2.** Mechanical and chemical analysis of the soils are shown in Appendix (**Tables 22 and 23**).

7.2 Experiment 1

The first experiment was laid out in a randomised complete block design, field number 2A with eight treatments. Each treatment was replicated four times. The experimental area was 1.0 hectare divided into 32 plots, the size of plot was 10m x 3.5m. The layout of the field is shown in **Figure 7.1.**

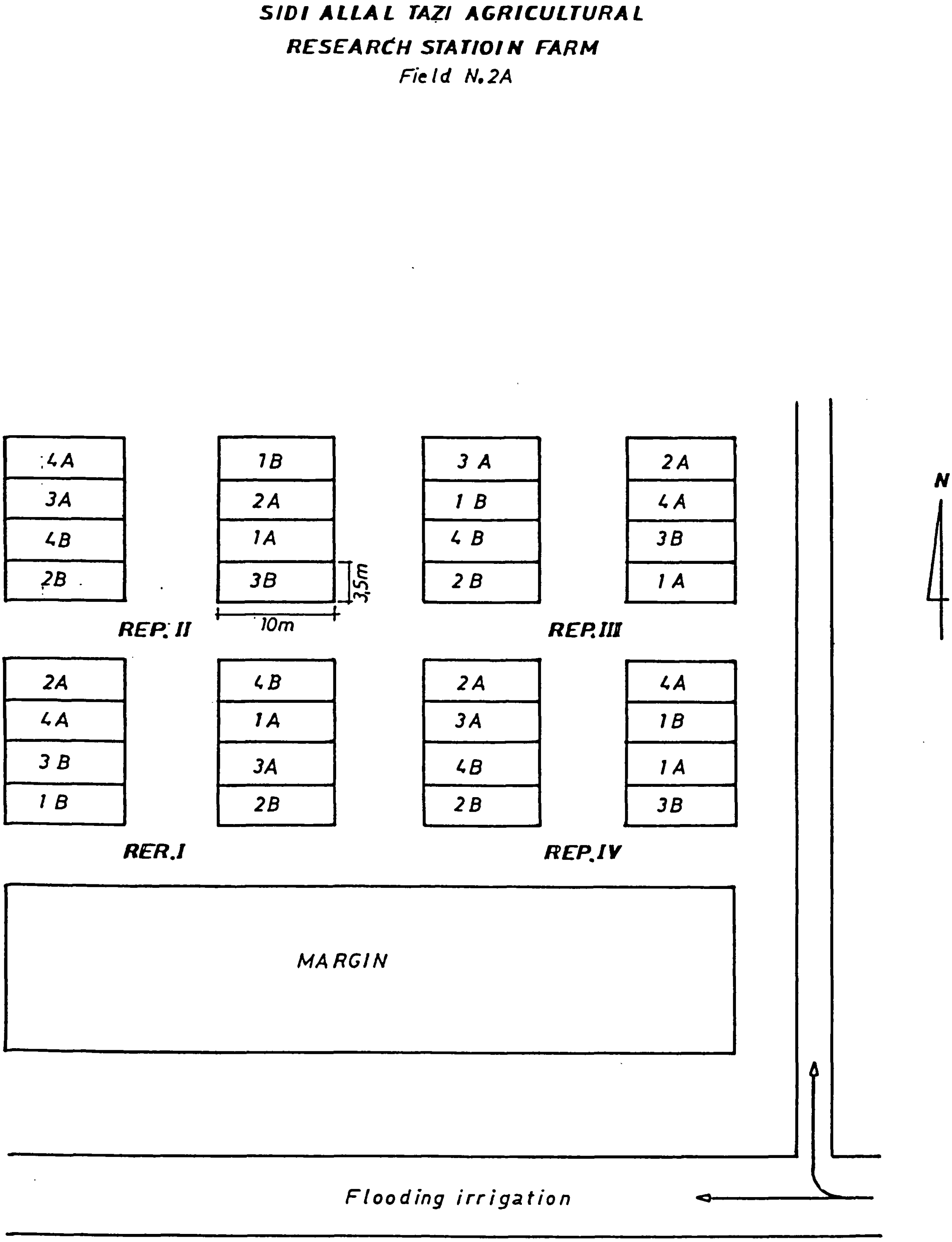
7.2.1 Seed-bed Preparation and Tillage Equipment

Land preparation started at the beginning of October 1994 with the burning and clearing of weed trash (**Plate 7.3**). Shallow ridging treatments of 5-7.5cm depth were carried out by using a 3-bodied local-made ridger with the effective width of 1.8m, borrowed from a farmer, pulled by a Fiat 640 tractor(65hp). On the 2nd November 1994, ridges were split by using the same ridger at a depth range of 5-7.5cm and exposing the soil which has been fallow for the previous three years. This is shown in **Plates 7.4** and **7.5** respectively. A diagram of ridge dimensions for ridging and ridge splitting operations is shown in **Figure 7.2.**

Fertilizers were applied by broadcasting manually on the soil surface of plots at recommended doses of 120kg/ha N (Ammonium Nitrate 33.5% N) distributed in three doses, 60kg/ha N before sowing, 30kg/ha N at the beginning of the tillering stage and the rest one month later; 80kg/ha Triple Superphosphate (45% P_2O_5) was also applied with the first dose of N.

Plate 7.1 The Experimental Area at Sidi Allal Tazi - Morocco.

Plate 7.2 Typical soil of the site, Cracky Vertisol.



Treatments :

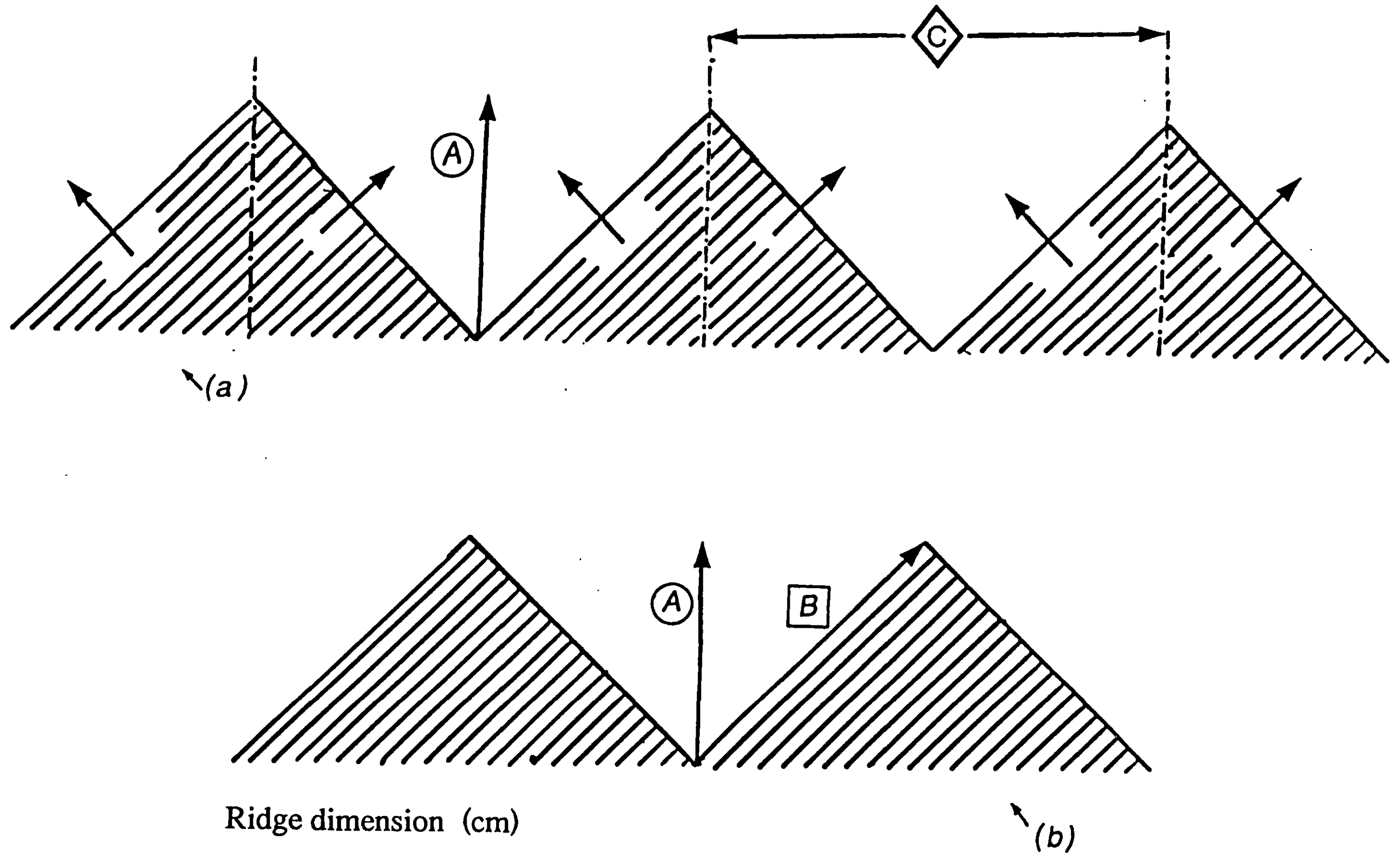
1 : Ridging+Ridge Splitting+Broadcasting+ CAMARA
2 : Ridging+Ridge Splitting+Drilling+CAMARA
3 : Ridging+Broadcasting+ CAMARA
4 : Ridging+ Drilling+ CAMARA
A : Seedrate 160 Kg/ha
B : Seedrate 140 Kg/ha

Figure 7.1 The Layout of Experiment 1.

Plate 7.3 Shows the marked experimental area after burning and manual clearing of weed trash.

Plate 7.4 Ridging operation showing use of concrete block as an aid to penetration of the soil.

Plate 7.5 Shows the shallow ridge splitting operation after exposing the soil surface for three days.



Ridge dimension (cm)

A · Ridge height **5 - 7.5cm**

B Shoulder length **10cm**

C Distance between centre line of ridges **80cm.**

Figure 7.2 A diagram of ridge dimensions, ridging and ridge splitting of reduced tillage system.
(a) soil position after ridging (b) soil position after ridge splitting

Dressed seed wheat, variety Achtar G2 was tested for germination in the laboratory. Results showed 97% germination. Variety Achtar G2 is recommended for locally sown crops under Semi-arid Moroccan conditions. It is similar to variety Debeira, which was sown under Gezira conditions in the Sudan, in its tolerance to heat stress (Hilali, H. Pers.Comm.).

The seed was drilled on 17.11.1994 at the two seed rates of 160kg/ha and 140kg/ha using a Sulky SMI mounted seed drill (France), drilling in 20cm wide rows at a depth of 5cm on flat land. The seed drill metering mechanism was the external fluted roller type and the effective width of the drill was 3m **(Plate 7.6)**. Seed broadcasting was carried out manually for the two seed rates of 160kg/ha and 140kg/ha for plots according to the layout of the experiment on the same day of drilling. A "Camara" levelling device was fabricated at the workshop of the Research Station, size of 3m x 4.5m and was used just after sowing to cover seed, firm and smooth the soil surface with some levelling and consolidation. This was pulled by 65hp Fiat 640 tractor **(Plate 7.7)**.

A mounted ditcher attached to a Massey Ferguson 399 tractor (90hp) was used to prepare the sub-main water channels **(Plate 7.8)**. Boundaries of the experimental area were lifted manually using spades to control the water over the field **(Plate 7.9)**. Flooding irrigation was applied through different sizes of concrete main water channels taking water lifted from Sebou river and distributing it into sub-main water channels to supply different farms **(Plate 7.10)**.

The first irrigation was on the same day as sowing and further applications at 14-20 day intervals depending on the weather conditions (see weather conditions in Appendix **Tables 24 to 27**). Anti fungus Printazol (0.75 l/ha) was sprayed twice by using a motorized sprayer; manual weeding was also done. Harvesting took place in the last week of May 1995. Samples were harvested manually, labelled and weighed in the laboratory.

Plate 7.6 Seed drilling with Sulky-SMI in operation.

Plate 7.7 The camara levelling device being used to press the soil and help in covering soil cracks prior to flooding irrigation.

Plate 7.8 A mounted ditcher being used to make the boundaries and sub-main channels for water supply.

Plate 7.9 The first flooding irrigation process.

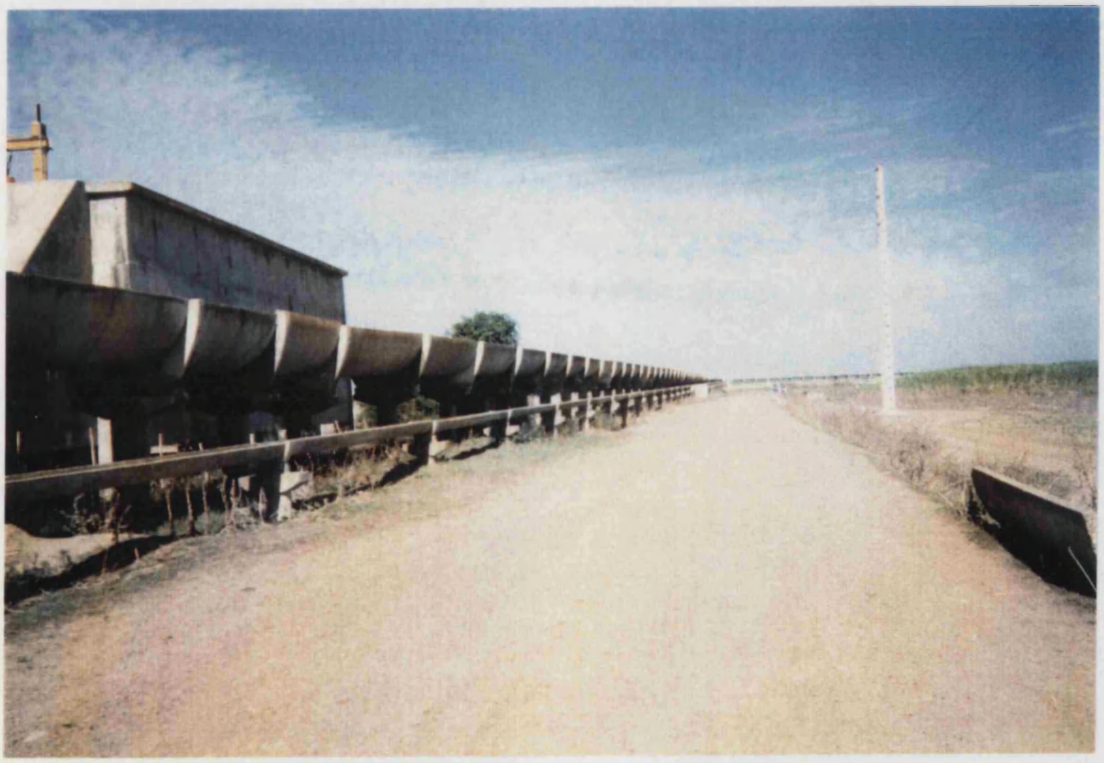


Plate 7.10 The water supply passing through different sizes of concrete channel.

7.3 Experiment 2

The second experiment was conducted at Sidi Allal Tazi Agricultural Research Station Farm, field number 2B. The design of the experiment was randomised complete block with six treatments. Each treatment was replicated three times. The experimental area was 0.5 hectare divided into 18 plots, the size of plot was 10.0m x 3.5m. The layout of the field is shown in **Figure 7.3.**

7.3.1 Seed-bed Preparation and Tillage Equipment

Seed-bed preparation started at the beginning of October 1994 with the burning and clearing of the weed trash.

7.3.1.1 Direct Drilling

A no-till Huard SD 300 grain drill (France), semi mounted with a row spacing of 15cm equipped with a set of twenty 43cm diameter rippled coulters and disc openers, with the effective width of 3m **(Plates 7.11 and 7.12)** attached to a Massey Ferguson 399 tractor (90hp) was used. This drilled at 5cm depth, dressed seed wheat, Achtar G2 cultivar, at the two seed rates of 160kg/ha and 140kg/ha, on 11.11.1994 according to the layout of the experiment. Fertilizers were applied at the same rates and timings as in experiment 1.

7.3.1.2 Conventional Tillage

Conventional tillage for wheat under Moroccan semi-arid conditions is to disc plough followed by disc harrowing twice in cross directions (Bourarash, Pers. comm.). Disc ploughing was carried out on 8.11.1994 using a reversible Massey Ferguson plough with three discs, 68cm diameter with effective width of 150cm, mounted on a 90hp Massey Ferguson 399 tractor **(Plate 7.13)** working at a depth of 25-30cm. After three days, disc harrowing at 10cm depth in cross directions was carried out using an offset mounted disc harrow with the effective width of 1.8m **(Plate 7.14)** pulled by Fiat 640 tractor (65hp). Fertilisers applied by broadcasting manually on the surface of the plots at recommended doses (120kg/ha N and 80kg/ha P), and the seed was drilled using the Sulky SMI seed drill on the same day at the two seed rates of 160kg/ha and 140kg/ha, these rates were 10 kg/ha more and less for comparing with farmers practice of 150kg/ha under semi-arid conditions in Morocco (Bourarach, Pers. comm).

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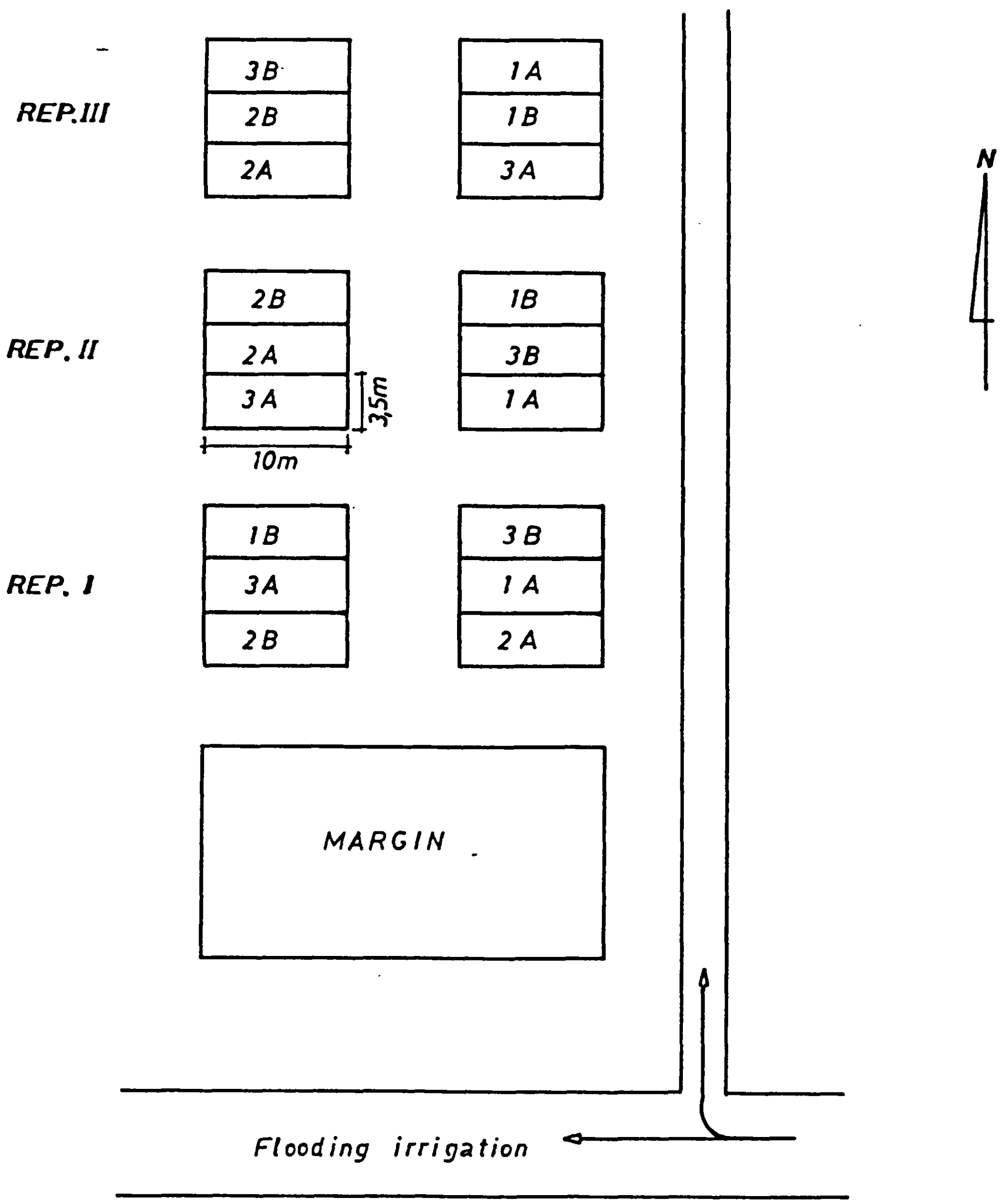
Field N.2B



Treatments :

1 : Direct Drilling
2 : Conventional Tillage
3 : Ridging+Broadcasting+CAMARA
A : Seedrate 160 Kg/ha
B : Seedrate 140 Kg/ha

Figure 7.3 The Layout of Experiment 2

Plate 7.11 A semi-mounted No-Till Huard SD 300 seed drill

Plate 7.12 Shows the direct drilling applied on the field

Plate 7.13 A reversible disc plough in operation as a first part of the conventional tillage of seed-bed preparation for wheat.

Plate 7.14 The disc harrow used as the integrated part of the conventional tillage.

7.3.1.3 Reduced Tillage

Shallow ridging was carried out on 8.11.1994 at a depth of 5-7.5cm and the soil left for three days. Fertilizer was applied by broadcasting manually at recommended doses (120kg/ha N and 80kg/ha P). Wheat seed Achtar G2 cultivar was broadcast manually at the two seed rate levels as mentioned earlier. A "Camara" levelling device was used to cover seeds, firm and smooth the soil surface with some levelling and consolidation. A mounted ditcher attached to a Massey Ferguson 399 tractor (90hp) was used to prepare the sub-main water channels. Boundaries of the experimental area were lifted manually to control irrigation water over the field.

The first irrigation was on the same day as sowing and further applications at 14-20 day intervals depending on the weather conditions (see weather conditions in Appendix - **Tables 24 to 27**). Anti-fungus Printazol (0.75 l/ha) was sprayed twice by using a motorised sprayer. Manual weeding was also done. Harvesting took place in the last week of May 1995. Samples were harvested manually, labelled, put into separate paper sacks and then taken to the laboratory for threshing and weighing.

7.4 Data Collection

The effects of different treatments on plant and soil physical properties were assessed by the following:

7.4.1 Soil Parameters

7.4.1.1 Measure of Soil Tilth

One function of many items of seed-bed preparation equipment is to reduce clod size. Cope and Patterson (1989) started to use a photographic technique as a routine method of assessing the effects of implements in a series of seed-bed preparation experiments. This technique was developed to reduce the labour demand associated with sampling and sieving and eventually a set of photographs was produced of different soil surfaces, calibrated against mean area diameter (M.A.D.), determinations arrived at using Van Bavel's Method (1949).

This technique was tried but proved unsuitable for the semi-arid soil conditions of Morocco. The technique which proved most suitable involved making up a wooden frame 1.0m^2 marked in 10cm divisions using black and white paints (**Plate 7.15**). Photographs were taken using the frame after each operation of seed-bed treatments and a visual comparison made.

Plate 7.15 Visual evaluation of tilth using sectioned frame.

7.4.1.2 Soil Strength

Soil strength was determined as resistance to penetration, it was measured periodically after the first irrigation when the soil was at field capacity (40% m.c.), at 8 and 13 weeks after sowing for each plot of both experiments. The penetrometer used was an Eijkelkamp Giesbeek (the Netherlands) shown in **Plate 7.16.** The instrument gave readings in kN/cm^2 these figures being converted to MPa by multiplying by 3.0. Readings were taken in four places on each plot to the depths of 5, 10, 15, 20, 25, 30, 40 and 50cm. It was used for measuring soil penetration resistance as described by Bradford (1986).

Soil moisture content was determined by taking three samples of 1kg each and drying in a laboratory oven for two days at 105°C.

7.4.1.3 Soil Bulk Density and Porosity

Soil bulk density was determined using the technique described by Blake (1965). A stainless steel cylinder 5cm diameter, 6cm height was used to measure soil bulk density (g/cm^3) for depths of 0-6, 6-12, 12-18, 18-24, 24-30 and 30-36cm by using the formula:

$$\mathbf{BD} = \frac{\mathbf{W}}{\mathbf{V}}$$

where, BD = Bulk Density of Soil (g/cm^3)
W = Dry Weight of Soil Sample (g)
V = Volume of Cylinder (cm^3)

Bulk density was measured after sowing and at 10 and 20 weeks after sowing for each plot of both experiments. A hole of 35 x 35cm was dug on each plot to let a small spade get into the hole, to get a soil sample to 36cm depth with the cylinder, Shown in **Plate 7.17.**

Soil samples were taken, dried in a laboratory oven and weighed to determine the moisture content. Samples of approximately 0.5kg were dried for 48 hours at 105°C. Soil porosity (%) was calculated for the same depths as for soil bulk density (g/cm^3) which were measured three times for both experiments, by using the formula:

$$\mathbf{SP} = \mathbf{100\left(1 - \frac{BD}{\sigma}\right)}$$

where, SP = Soil Porosity (%)
BD = Soil Bulk Density (g/cm^3)
σ = Soil Real Density (g/cm^3)

(which is approximately 2.65 for most vertisols under arid and semi-arid conditions)

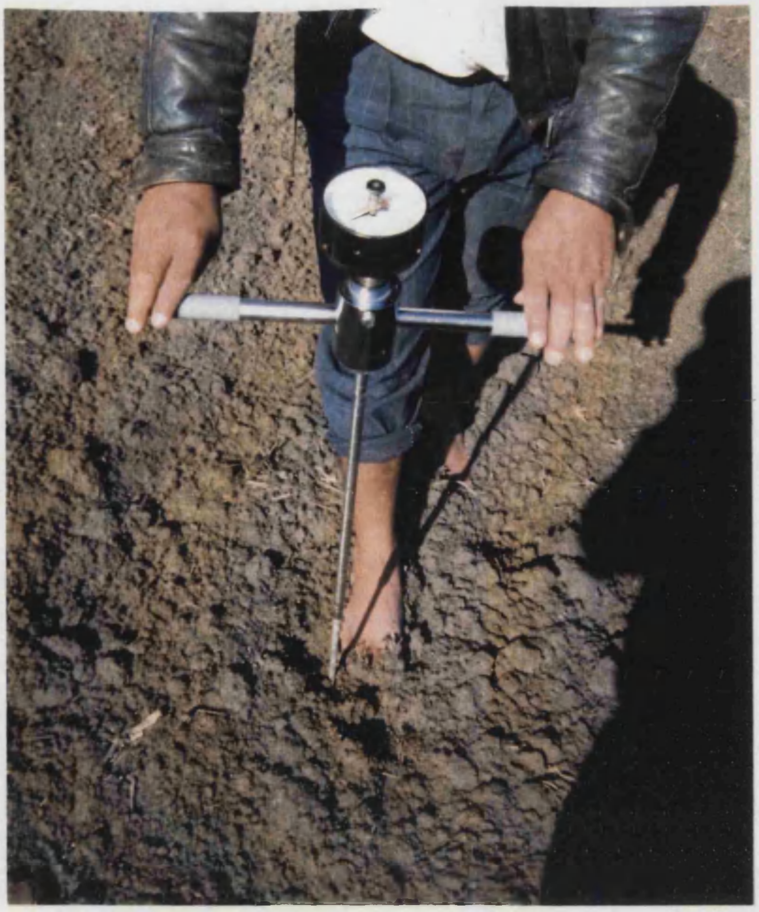


Plate 7.16 Eijkelkamp Penetrometer in use.

Plate 7.17 Driving in the stainless steel cylinder for measurement of soil bulk density.

7.4.2 Machine Parameters

An Autotronic Massey Ferguson - 3080 tractor (92hp) shown in **Plate 7.18**, equipped with Lax 55 multi purpose intelligent digital data logger **(Plate 7.19)** and central processing unit to measure machine performance for different implements was used in field operations, such as seed-bed preparation. Measurement of draught force, engine speed, fuel consumption, forward speeds and wheel slip were taken when using traditional Moroccan tillage implements, when using the reduced tillage technique of shallow ridging and splitting and when direct drilling.

A test distance of 50m in the experimental area was indicated by using two range poles **(Plate 7.20)**. The autotronic tractor was provided with a radar system **(Plate 7.21)** to indicate automatically the start of the test distance and start the data logger collecting and recording the required data until it reached the second range pole where it stopped taking data automatically. Data was taken and recorded every 50 millisecond, and each test for the different equipment used for both experiments was repeated four times. The Lax-Transformation Release 3 version 2.2 program was used to process the collected data.

7.4.2.1 Draught Force (kN/m)

Mounted equipment was attached to the 3 point hydraulic system of the autotronic tractor to measure power requirement for different implements. The angle of the top link of the hydraulic system was adjusted using an inclinometer **(Plate 7.22)** to adjust the operating position of the attached implement vertically and horizontally **(Plate 7.23)**. Draught force was determined from left and right bottom links and the top link for each item of equipment in the operation position.

7.4.2.2 Tractor Engine Speed (rev/min)

The autotronic tractor was provided with a sensor to indicate the engine speed during the operating test distance. The data taken were recorded through the digital data logger and calculated in differences of impulses per cycle as in the following formula:

$$\Delta F = F_{(i+1)} - F_{(i)}$$

where ΔF = revolutions per millisecond

$F_{(i+1)}$ = revolutions reading at end of every 50 milliseconds.

$F_{(i)}$ = revolutions reading at beginning of every 50 milliseconds

Plate 7.18 Massey Ferguson tractor used in the field experiments.

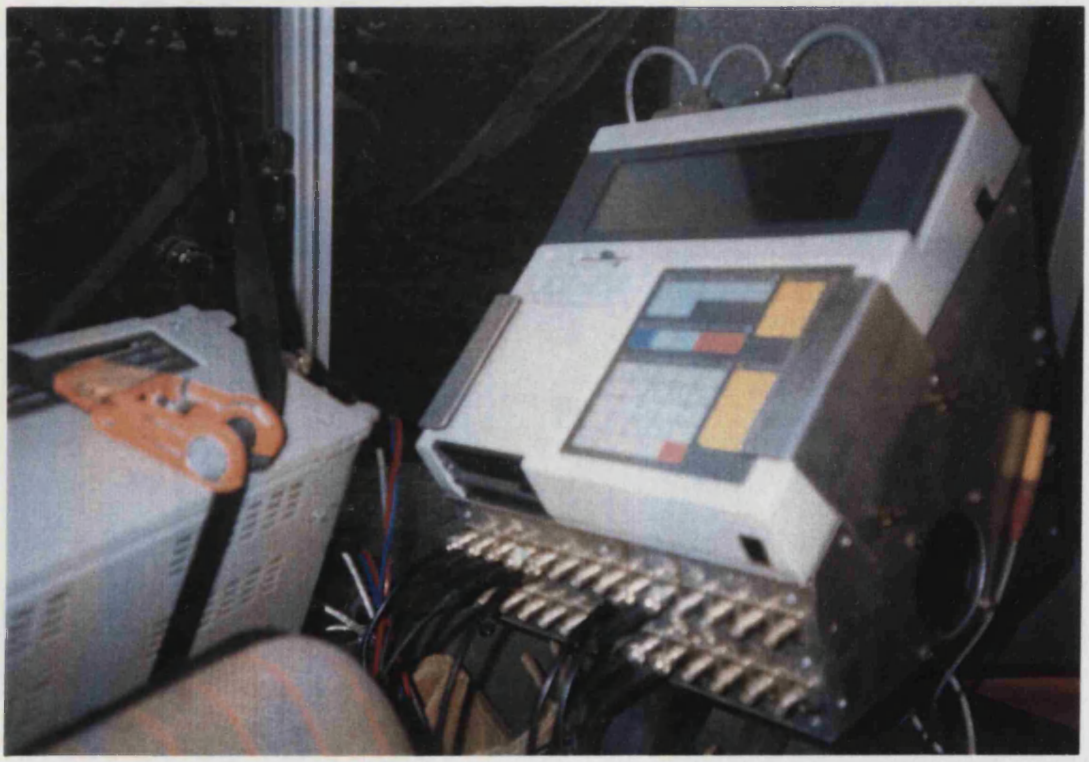


Plate 7.19 Data Logger and Central Processing Unit fitted to Massey Ferguson tractor.

Plate 7.20 Range poles being used to mark out distances for tests using Massey Ferguson Autotronic Tractor.

Plate 7.21 Radar attachment used for switching data logger on and off at range poles.

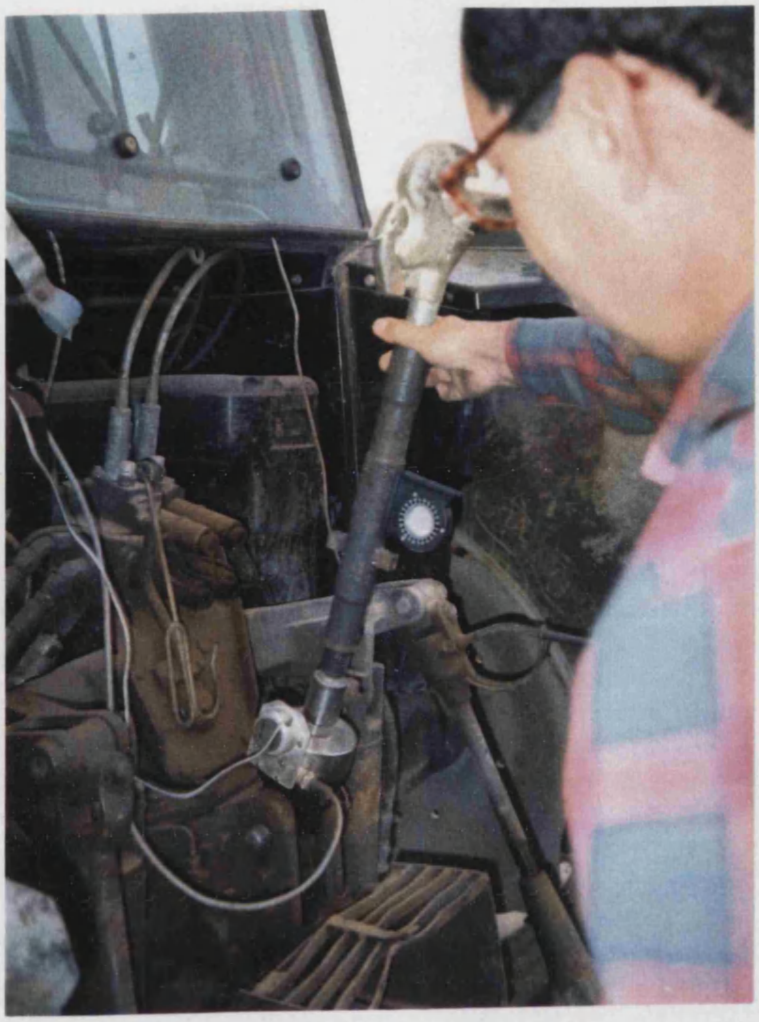


Plate 7.22 Inclinometer and strain gauge unit attached to tractor top link.

Plate 7.23 Sensor units fitted to the tractor 3 point-linkage.

7.4.2.3 Fuel Consumption (l/h)

An electronic fuel consumption device was fixed on the Autotronic tractor (**Plate 7.24**) to measure the fuel consumption in l/h for the operation of different implements used for both experiments was recorded. The device providing readings according to a range of volts as follows:

0 – 60 l/h = 0 – 9 V where, l/h = fuel consumption in litres per hour
V = estimated fuel consumption by electronic device in volts

7.4.2.4 Theoretical and Actual Forward Speed (km/h)

Theoretical and actual operation speeds were measured, for different equipment used for both experiments, in km/h. Optimum actual operation speed is the most important to achieve a good seed-bed at specific soil moisture contents. Data for wheel slip for each run was collected during the operation test distance (50m), and the wheel slip (%) was calculated using the formula:

$$WS = \frac{S_{th} - S_{ac}}{S_{th}} \times 100$$

where, WS = wheel slip (%)
S_{th} = Theoretical operation speed with no load (km/h)
S_{ac} = Actual operation speed with no load (km/h)

Tractor performance measurements were taken for the different implements used for the different conventional tillage (disc plough, offset disc harrow), direct drilling, conventional drilling, reduced tillage (ridging and ridge splitting).

Plate 7.24 Electronic fuel consumption measuring device

7.4.3 Crop Parameters

Field measurements for both experiments were carried out during the growing season as follows:

7.4.3.1 Plant Count (plant/m^2)

Plant counts were taken weekly, from the first week after sowing until 10 weeks later by using a frame of size 33 x 33cm ($0.1m^2$) **Plate 7.25.** In the first instance seven frames were randomly placed and counted on each plot for both experiments. Subsequently, the frames were placed in the same positions on each occasion.

7.4.3.2 Leaf and Tiller Development

Ten plants were selected per plot for both experiments and labelled from 1–10 (**Plate 7.26**). Measurements were taken weekly from the first week after sowing until 12 weeks later to assess development on vegetative growth by counting every week the total number of leaves on the main stem, total number of stems per plant.

Netting of plots is shown in **Plate 7.27** and **7.28.** Both experiments were covered early to avoid bird damage which is common and often starts at the milky stage of the grain.

7.4.3.3 Yield and Components

Harvesting time started at the end of May 1995, and the grain moisture content was 14% on the field. Fifty ears per plot were randomly harvested by hand, labelled and put into separate paper sacks for threshing and weighing in the laboratory. The number of ears were counted 10 times by using the 33 x 33cm frame ($0.1m^2$) for each plot of both experiments and recorded.

Harvesting measurements included number of ears per square metre, weight per ear and grain yield (kg/ha).

Plate 7.25 Showing plant count frame.

Plate 7.26 Showing markers for 10 selected plants per plot

Plate 7.27 Netting over plots to control bird damage

Plate 7.28 Plots with crop near harvest time

7.5 Operation Costs

Measurement of tractor performance for implements used for both experiments was assessed to indicate the field operation costs of establishing wheat under semi arid vertisols conditions of Morocco. Unfortunately fixed costs such as depreciation, interest in capital invested, insurance, taxes etc were not recorded as the information was not available even in the Agricultural Research Stations over the country. This is a similar situation in the Sudan. However, the likely fixed costs in the UK were calculated to provide a basis for comparison.

The operation cost of the tractor with selected implements for both experiments were determined in Moroccan Dirhams per hectare (Dh/ha).

In Morocco there are co-operative machinery groups from which machinery can be hired and also it is possible to hire from private farmers. The charges vary depending on the type of equipment, field condition, area of land to be worked and time during the agricultural season. Charge for equipment hiring estimated in Dh/ha (Bourarach and Hilali, pers. comm.).

7.6 Weather Data

Maximum and minimum temperature (^{o}C) and rainfall during the growing season of 1994/95 were collected from Sidi Allal Tazi Meteorological Station and compared with the same data for the previous growing seasons. This is shown in the Appendix **(Tables 24 to 27)**.

8.0 RESULTS

8.1 Soil Physical Properties

Tillage generally improves soil conditions for plant growth, especially under circumstances of high strength and compaction.

8.1.1 Soil Aggregate Distribution

Six sample photographs (**Plates 8.1 to 8.6**) of both experiments were taken at random during seed-bed preparation operations with different implements, using the frame of $1.0m^2$ marked in 10cm divisions using black and white paints, thus showing the different soil surfaces produced.

8.1.2 Soil Bulk Density and Porosity

(a) EXPERIMENT 1 (FIELD 2A)

The soil bulk density values in plots of reduced tillage treatments after sowing ranged between 1.04 and 1.38 g/m^3 within the measured depths (0 - 36cm depth) (**Figure 8.1**). There was no significant difference in dry bulk density between ridging and ridge splitting treatments at different depths. At the beginning of the growing season, ten weeks after sowing (**Figure 8.2**), there were significant differences ($P<0.05$) in bulk density between treatments. Ridging treatments always showed higher bulk density values than ridge splitting in the plots for all depths, except for 12-18cm depth.

At twenty weeks after sowing (**Figure 8.3**), there were significant differences ($P<0.01$) between treatments with interaction of sowing methods (broadcast and drilling). Ridging treatment with broadcast seed started with higher bulk density values, while ridge splitting treatment with broadcast seed was always lower than ridging treatment with broadcast seed for all depths. Bulk density values increased gradually at depths of 12-18cm and 18-24cm; however, values increased markedly at depths of 24-30cm and 30-36cm.

Plate 8.1 Soil after ridging operation.

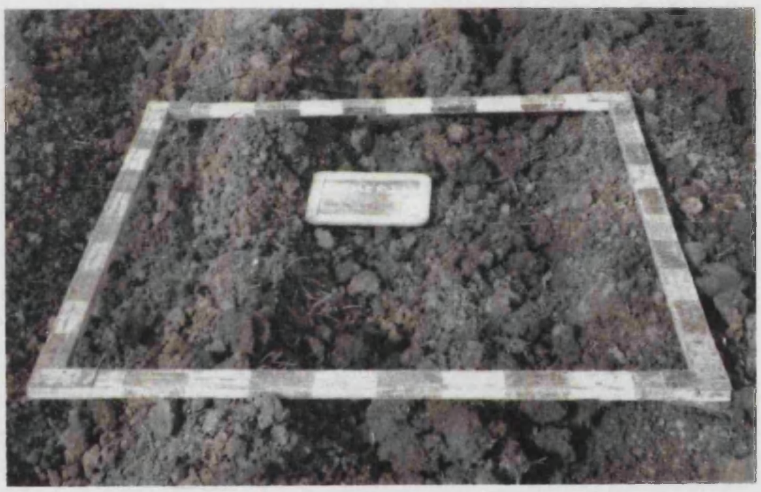


Plate 8.2 Same soil after ridge splitting.

Plate 8.3 Same soil after use of Camara.

Plate 8.4 Soil after disc ploughing.

Plate 8.5 Soil after disc harrowing.

Plate 8.6 Soil after drilling operation.

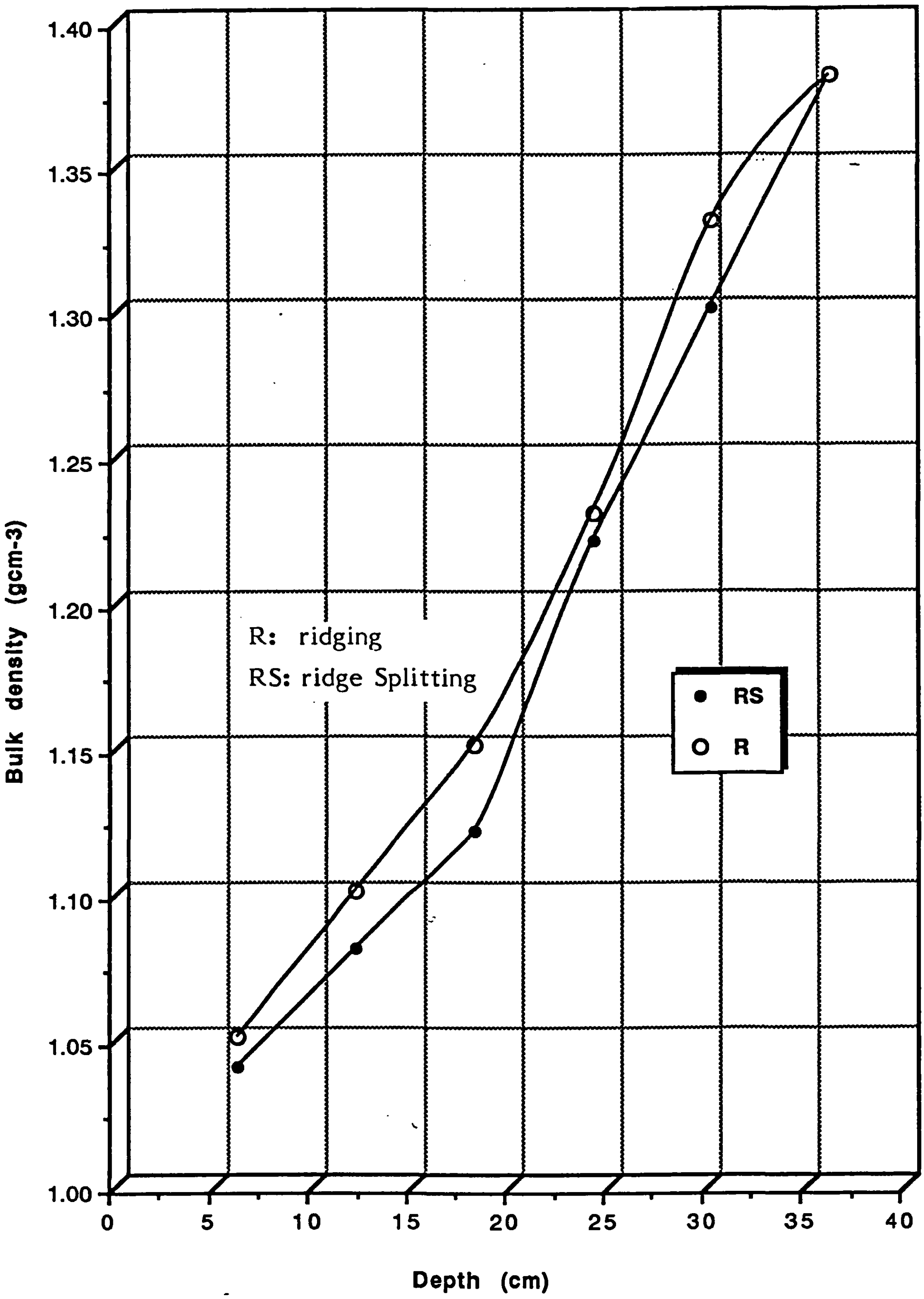


Figure 8.1 Effect on soil bulk density of Reduced Tillage practices after sowing.

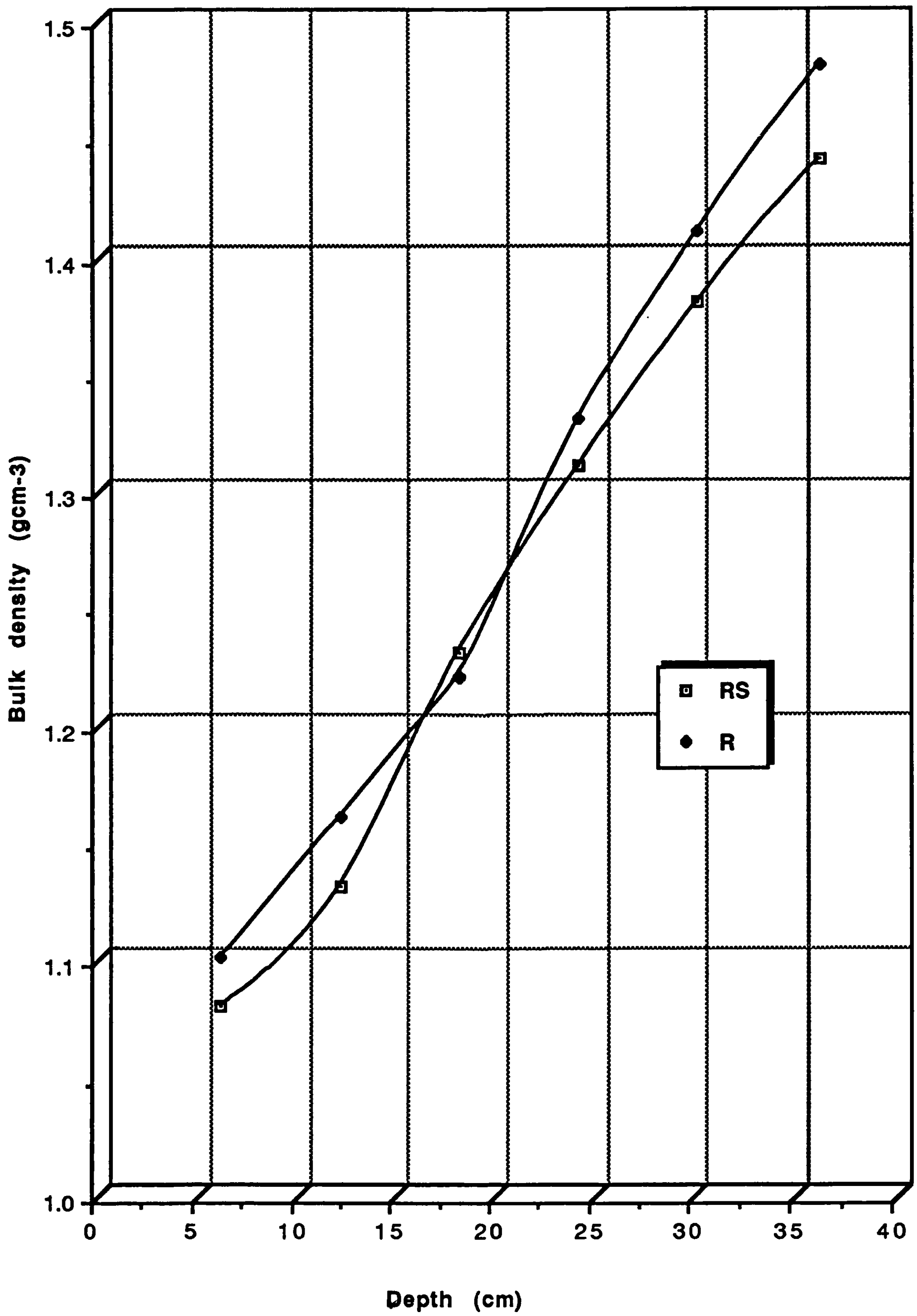


Figure 8.2 Effect on soil bulk density of Reduced Tillage practices at 10 weeks after sowing.

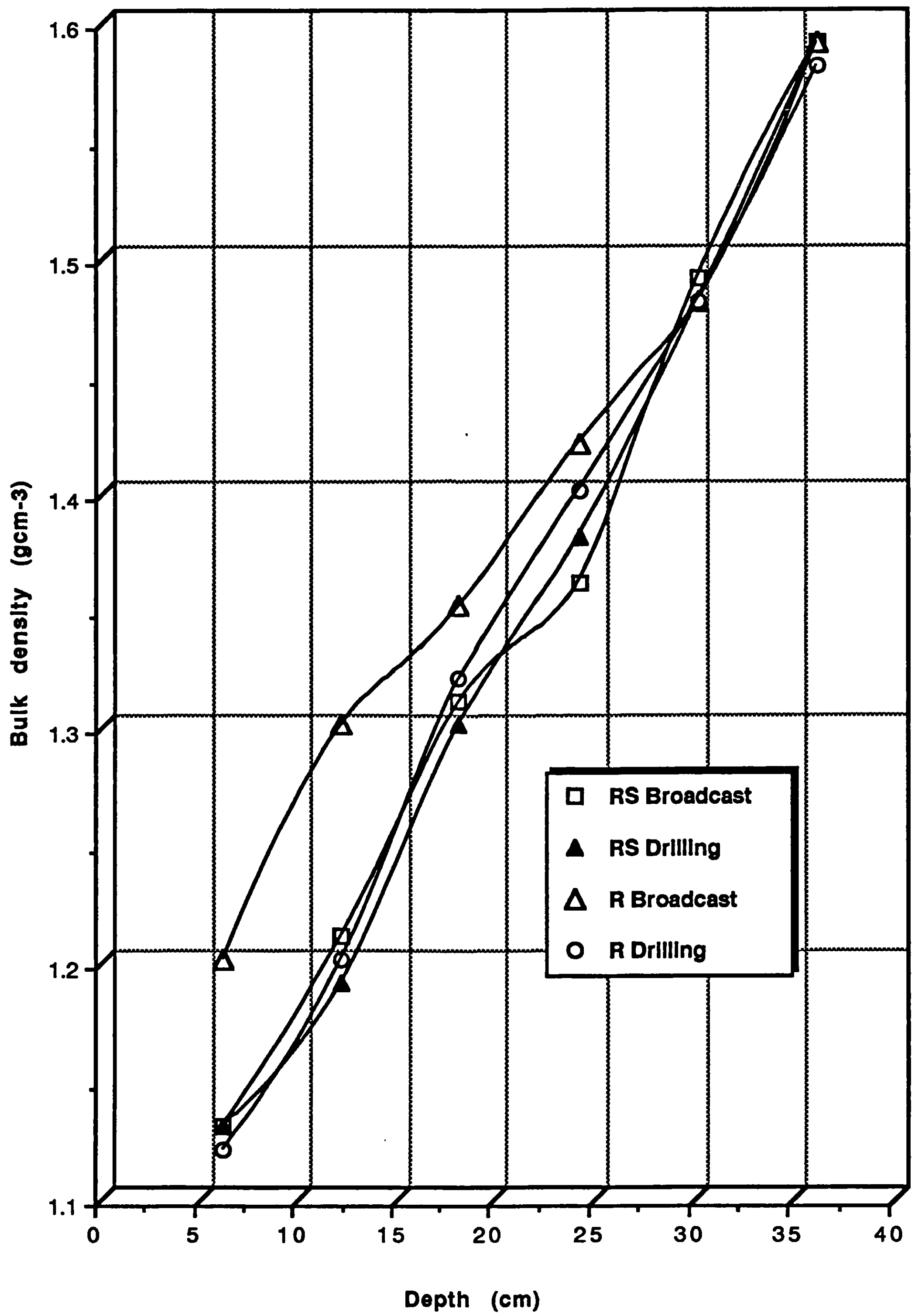


Figure 8.3 Effect on soil bulk density of Reduced Tillage practices and sowing methods at 20 weeks after sowing.

The effect of soil porosity was recorded simultaneously with the bulk densities after sowing **(Figure 8.4)**.

At ten weeks after sowing **(Figure 8.5)**, there were significant differences ($P<0.05$) in the values of soil porosity between treatments, according to the soil bulk density. At twenty weeks after sowing **(Figure 8.6)**, there were significant differences ($P<0.01$) between ridging and ridge splitting treatments on soil porosity values with interaction of sowing methods, in the same soil samples taken for bulk density measurement. Soil porosity values in the plots were always higher at the soil surface.

(b) EXPERIMENT 2 (FIELD 2B)

The effect of different tillage systems on soil bulk density after sowing showed highly significant differences ($P<0.001$). Bulk density increased with depth **(Figure 8.7)**. The reduced tillage treatment (ridging only) was slightly higher than the conventional tillage treatment, in the average of bulk densities at different depths. However, the highest bulk density values were observed with the direct drilling treatment, particularly at depths of 6-12cm and 24-30cm, with values of 1.44g/cm^3 and 1.46g/cm^3 respectively. Bulk density values with direct drilling were variable within different depths.

At ten weeks after sowing **(Figure 8.8)** the effect of different tillage systems on bulk density showed highly significant differences ($P<0.001$) and the values increased with depth for the different tillage systems applied. However, the direct drilled treatments maintained their variability at different depths, while reduced tillage resulted in higher values of bulk density below the depth of 18-24cm.

By the end of the growing season, twenty weeks after sowing, there were significant differences ($P<0.001$) between different tillage systems **(Figure 8.9)**. Bulk density values were increased generally at different depths, even with conventional tillage which started with higher values of bulk density than reduced tillage up to a depth of 18-24cm; direct drilling treatment plots showed a marked increase in bulk density values below the depth of 18-24cm.

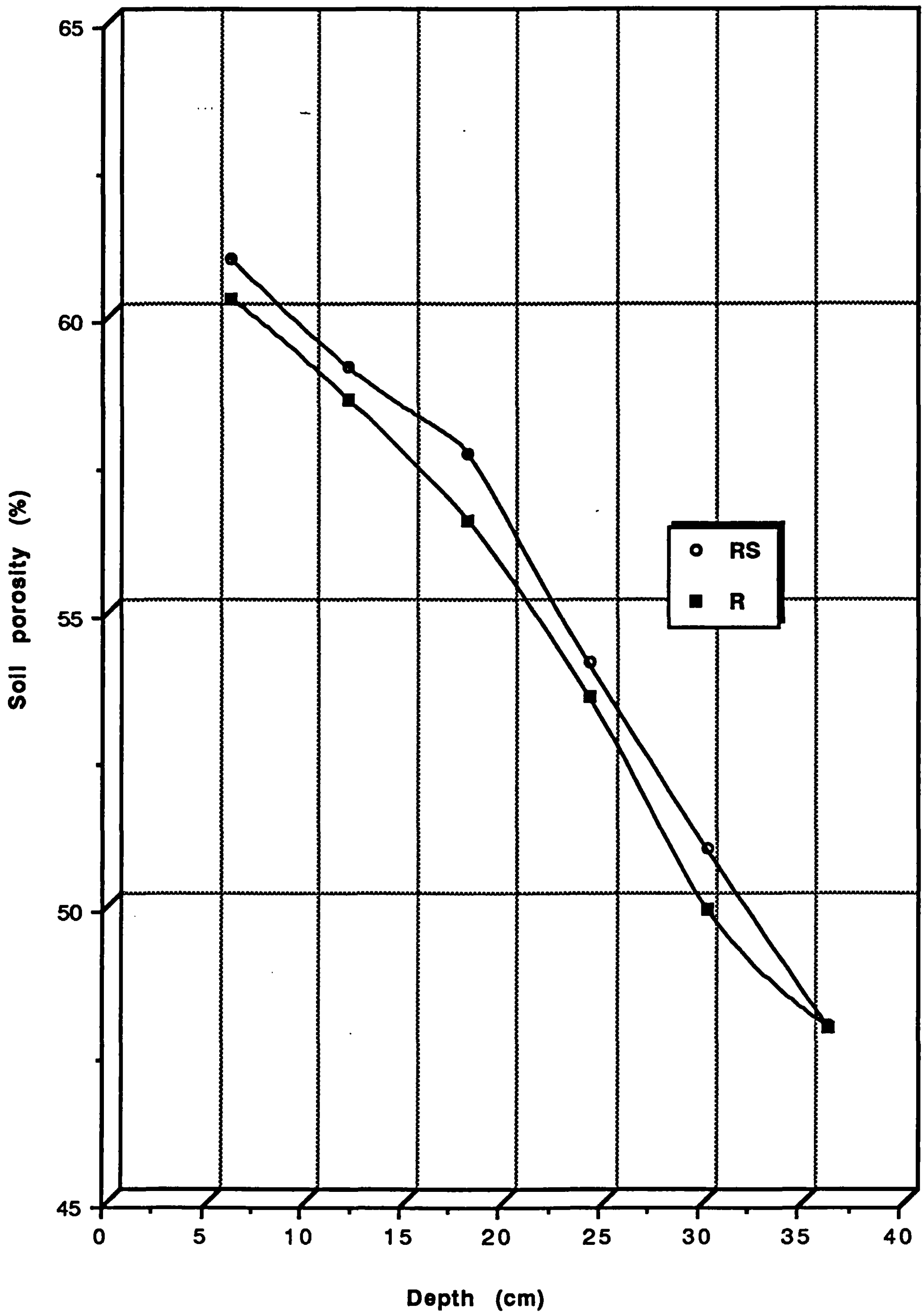


Figure 8.4 Effect on soil porosity of Reduced Tillage practices after sowing.

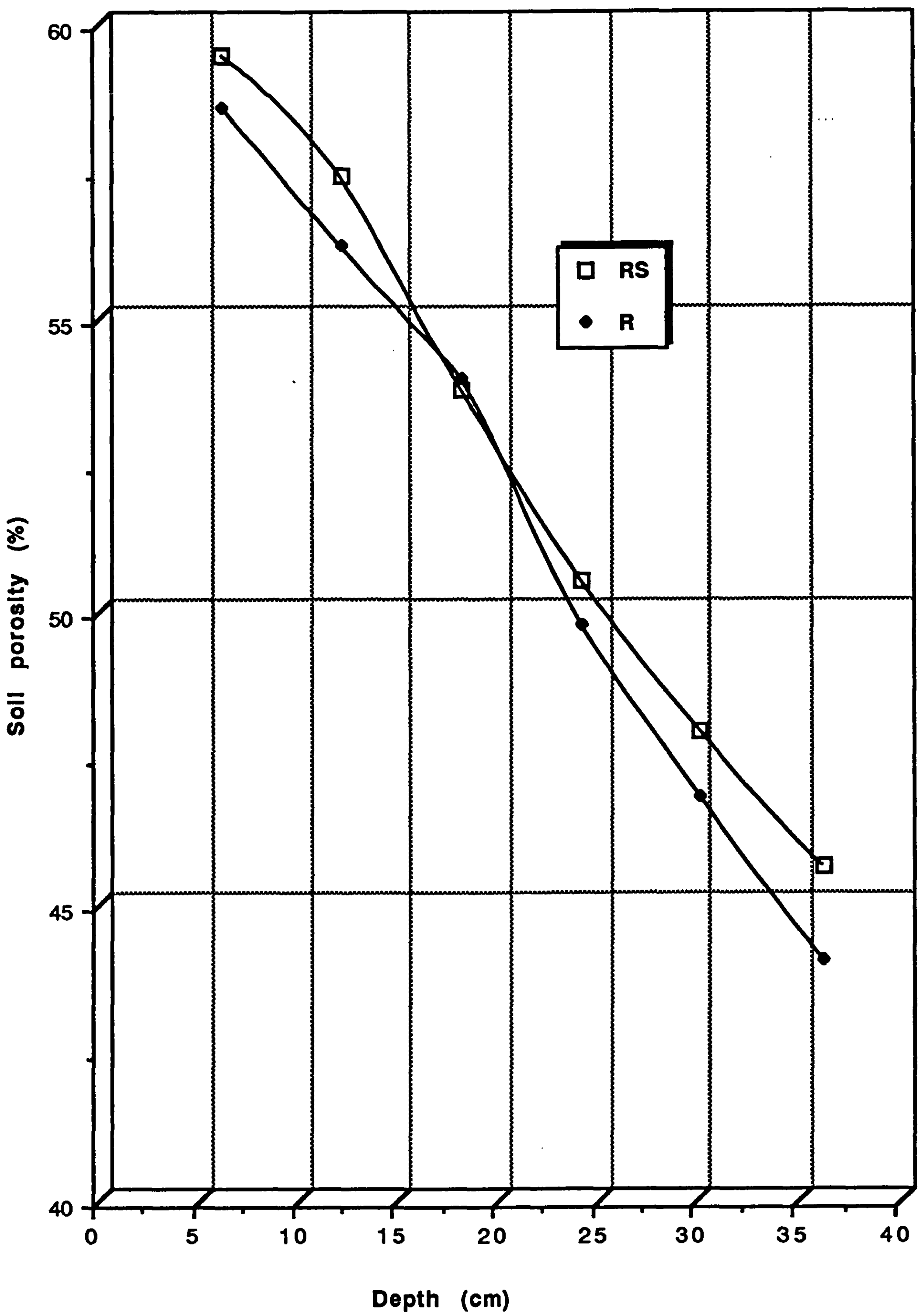


Figure 8.5 Effect on soil porosity of Reduced Tillage practices at 10 weeks after sowing.

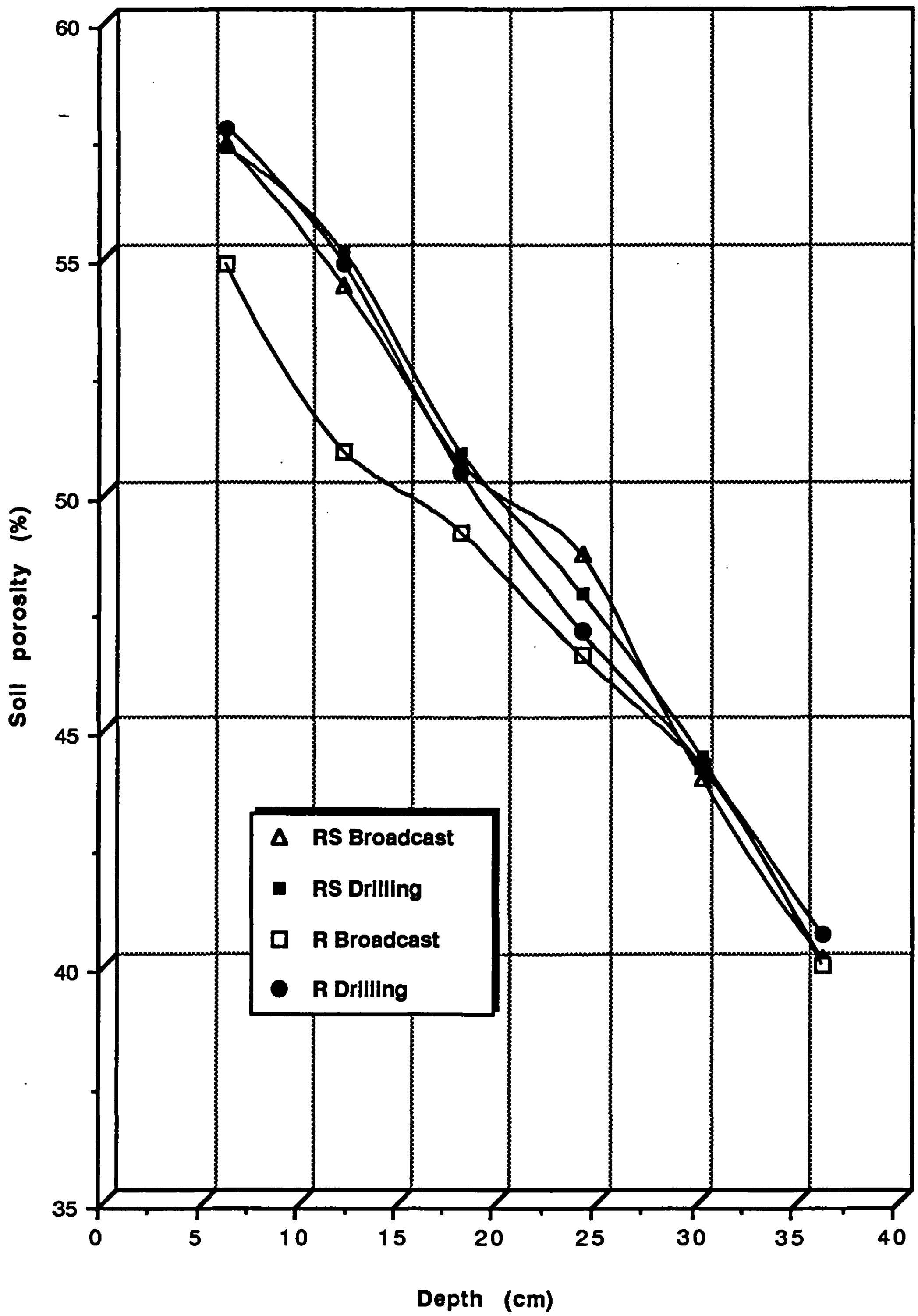


Figure 8.6 Effect on soil porosity of Reduced Tillage practices and sowing methods at 20 weeks after sowing.

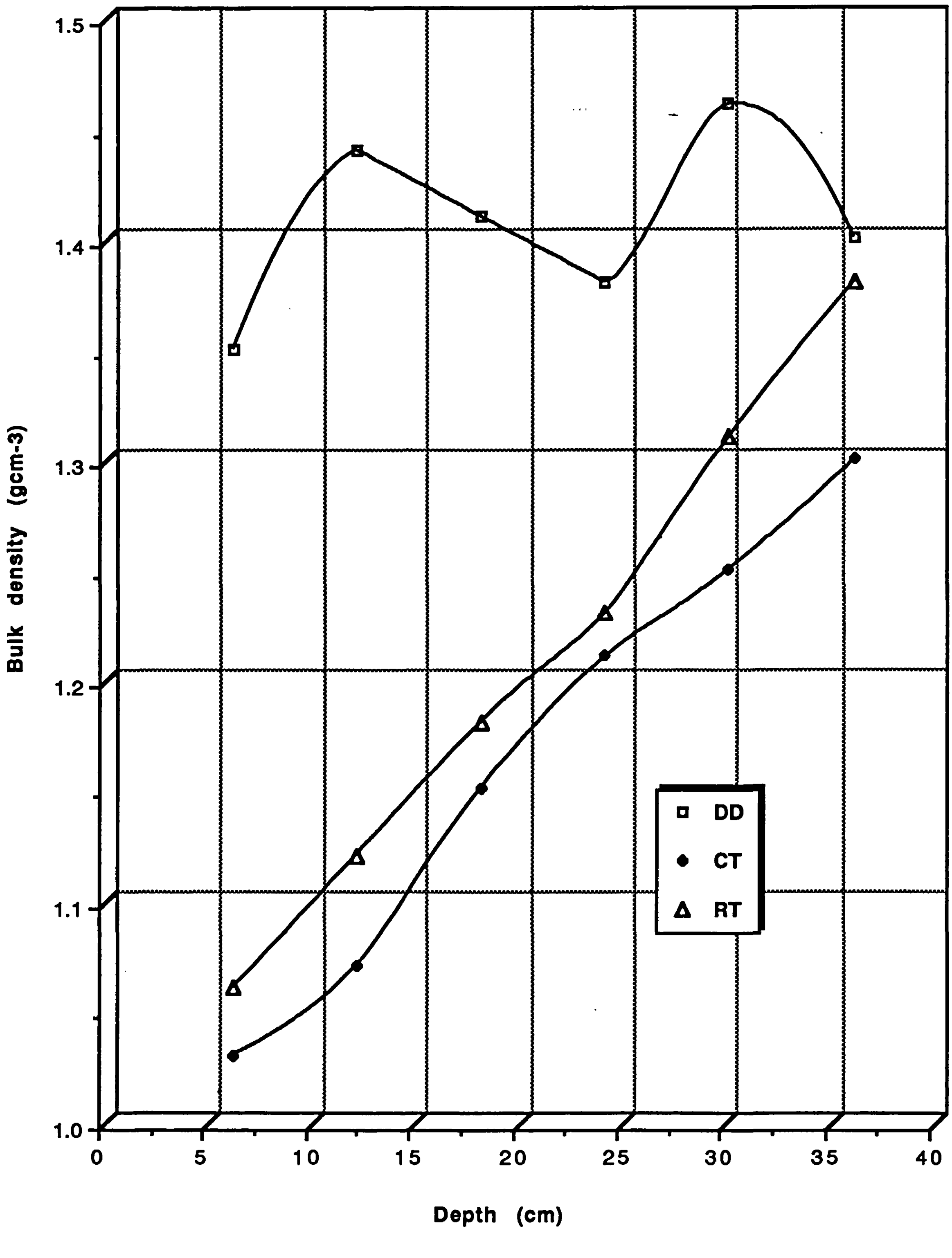


Figure 8.7 Effect on soil bulk density of different tillage systems after sowing.

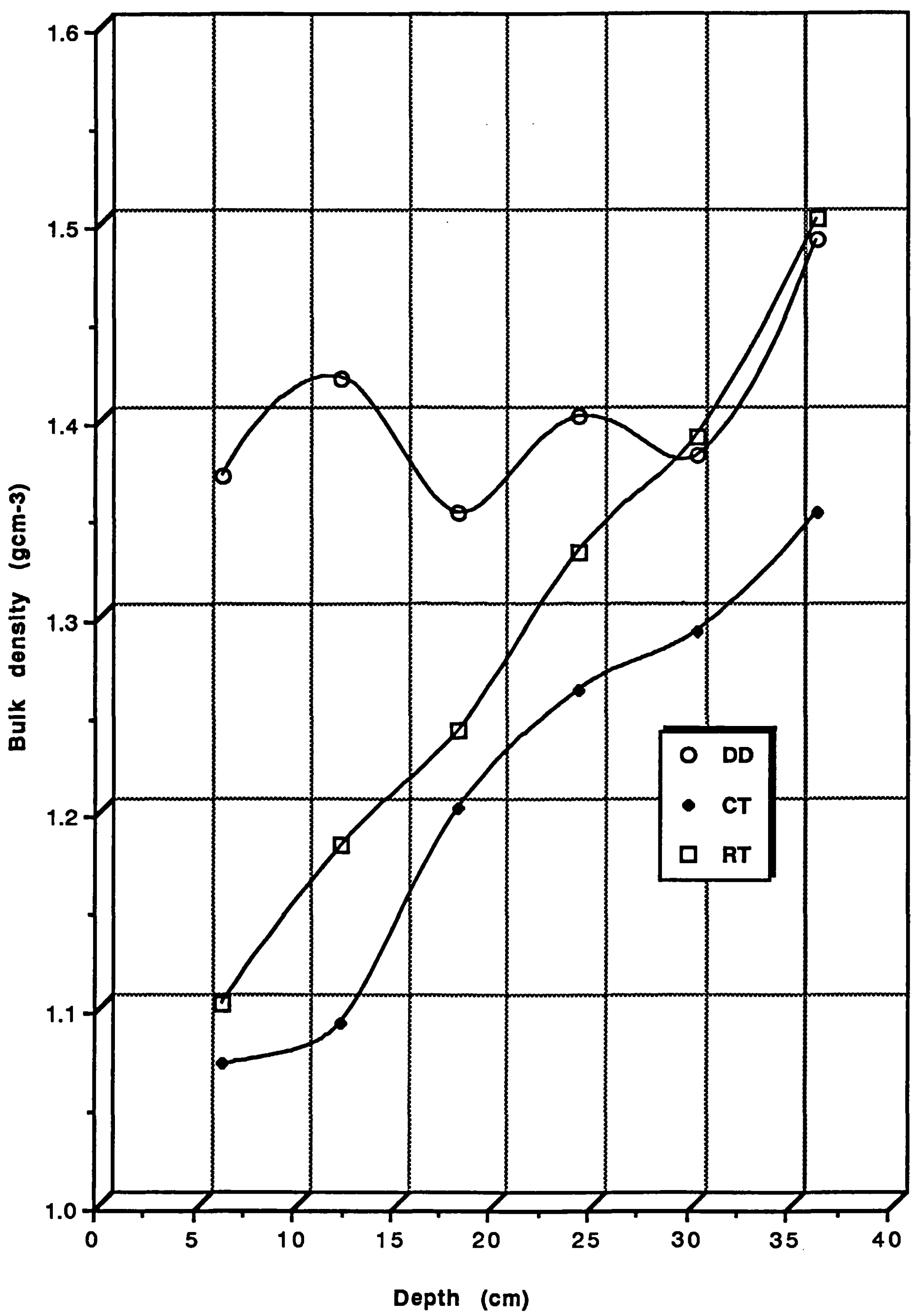


Figure 8.8 Effect on soil bulk density of different tillage systems at 10 weeks after sowing.

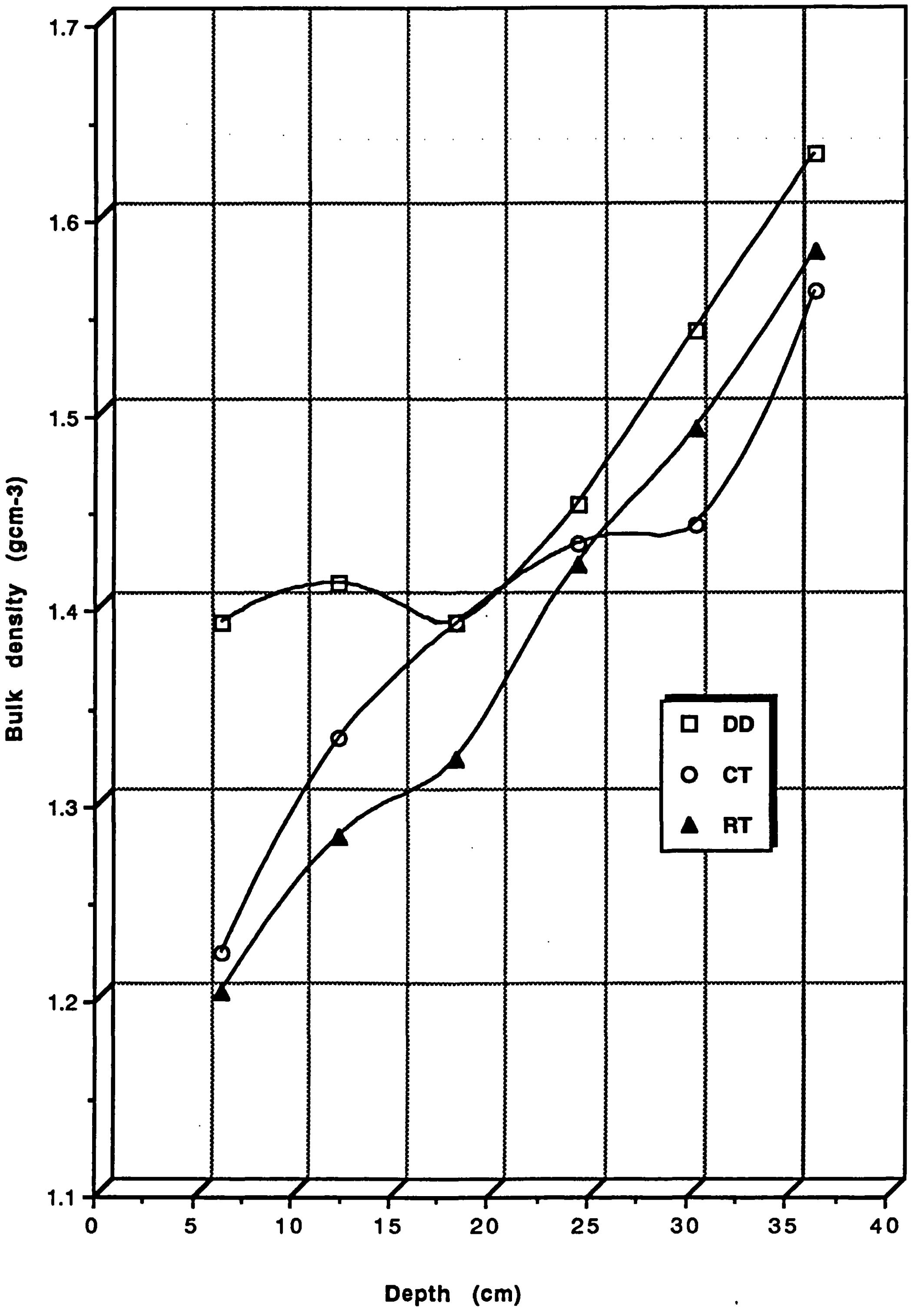


Figure 8.9 Effect on soil bulk density of different tillage systems at 20 weeks after sowing.

All tillage practices appeared to influence pore space by increasing the average porosity of the cultivated layers. Porosity then decreased subsequent to flooding irrigation intervals, with highly significant differences ($P<0.001$) for all test occasions in the average of porosity values according to soil bulk density (**Figures 8.10, 8.11 and 8.12**).

8.1.3 Soil Penetration Resistance (SPR)

(a) EXPERIMENT 1

Reduced tillage practices and seed rates in relation to soil penetration resistance after the first irrigation showed significant differences ($P<0.05$) (**Figure 8.13**). On all plots, penetration resistance values increased markedly up to 30cm depth and then more gradually at 40cm depth except for the ridge splitting with 160kg/ha seed rate treatment which continued to increase markedly. The ridge splitting treatment showed considerable differences between seed broadcasting and seed drilling (**Table 8.1**) with highly significant differences between tillage and sowing method interaction ($P<0.001$). At eight weeks after sowing, on the plots of tillage practices associated with broadcasting and seed rates, there were highly significant differences ($P<0.001$) in penetration resistance values, which were increased for different treatments with some variation in values at the upper layer of vertisol (20-30cm) (**Figure 8.14**). However, the same layer of soil with drilling (**Figure 8.15**) for different treatments had some clear variation in penetration resistance values with significant differences ($P<0.001$) for the other depths which were increased generally.

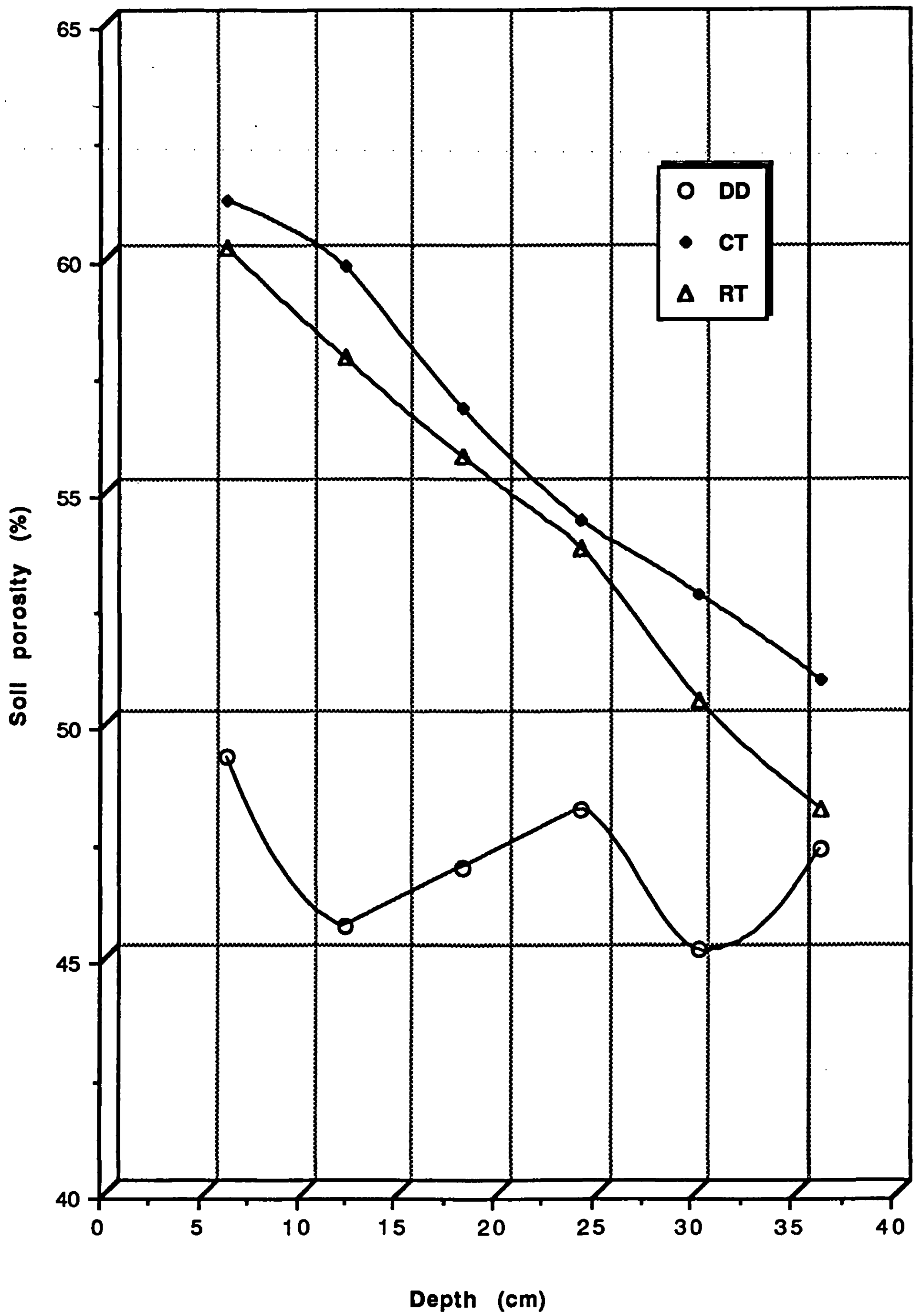


Figure 8.10 Effect on soil porosity of different tillage systems after sowing.

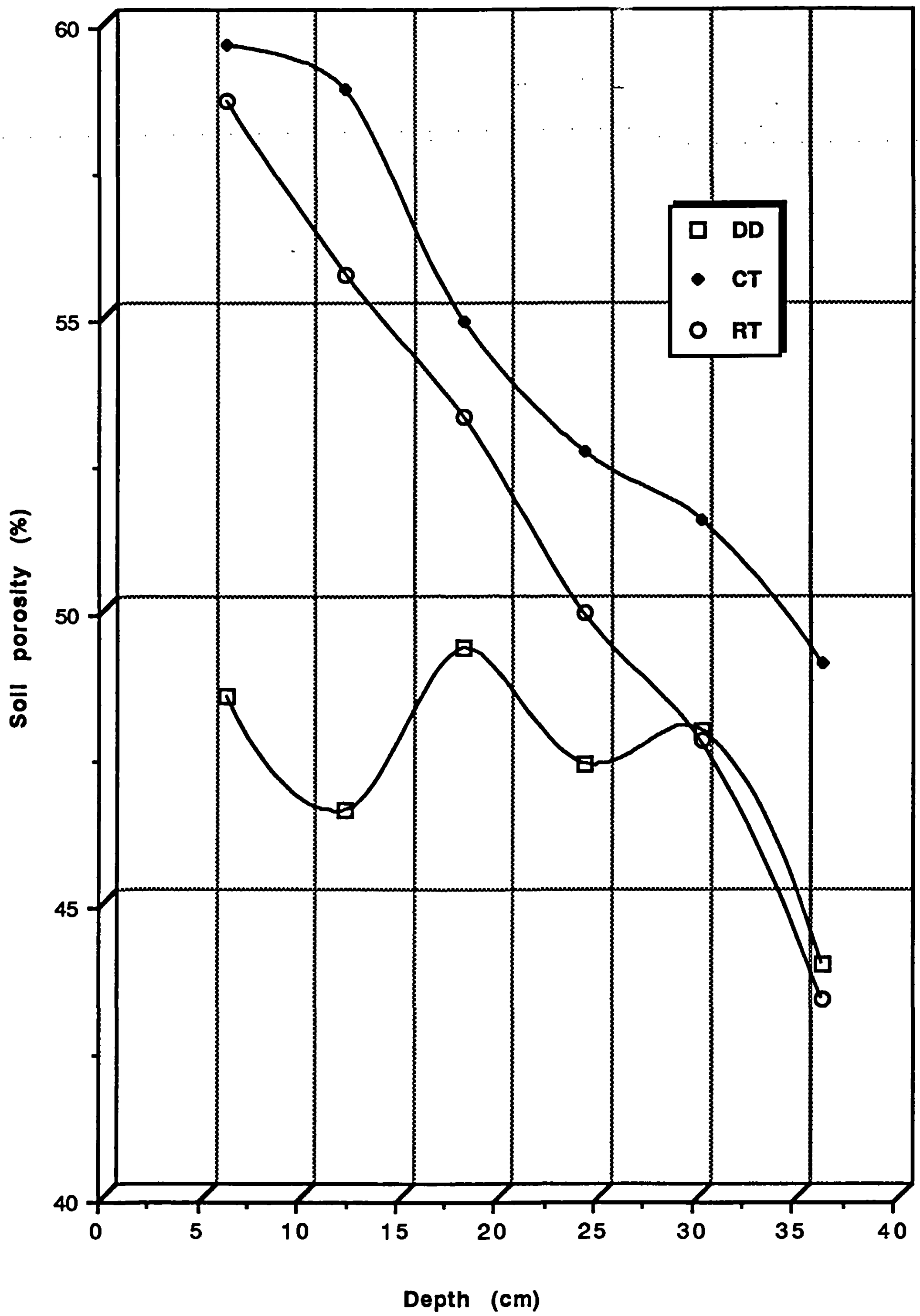


Figure 8.11 Effect on soil porosity of different tillage systems at 10 weeks after sowing.

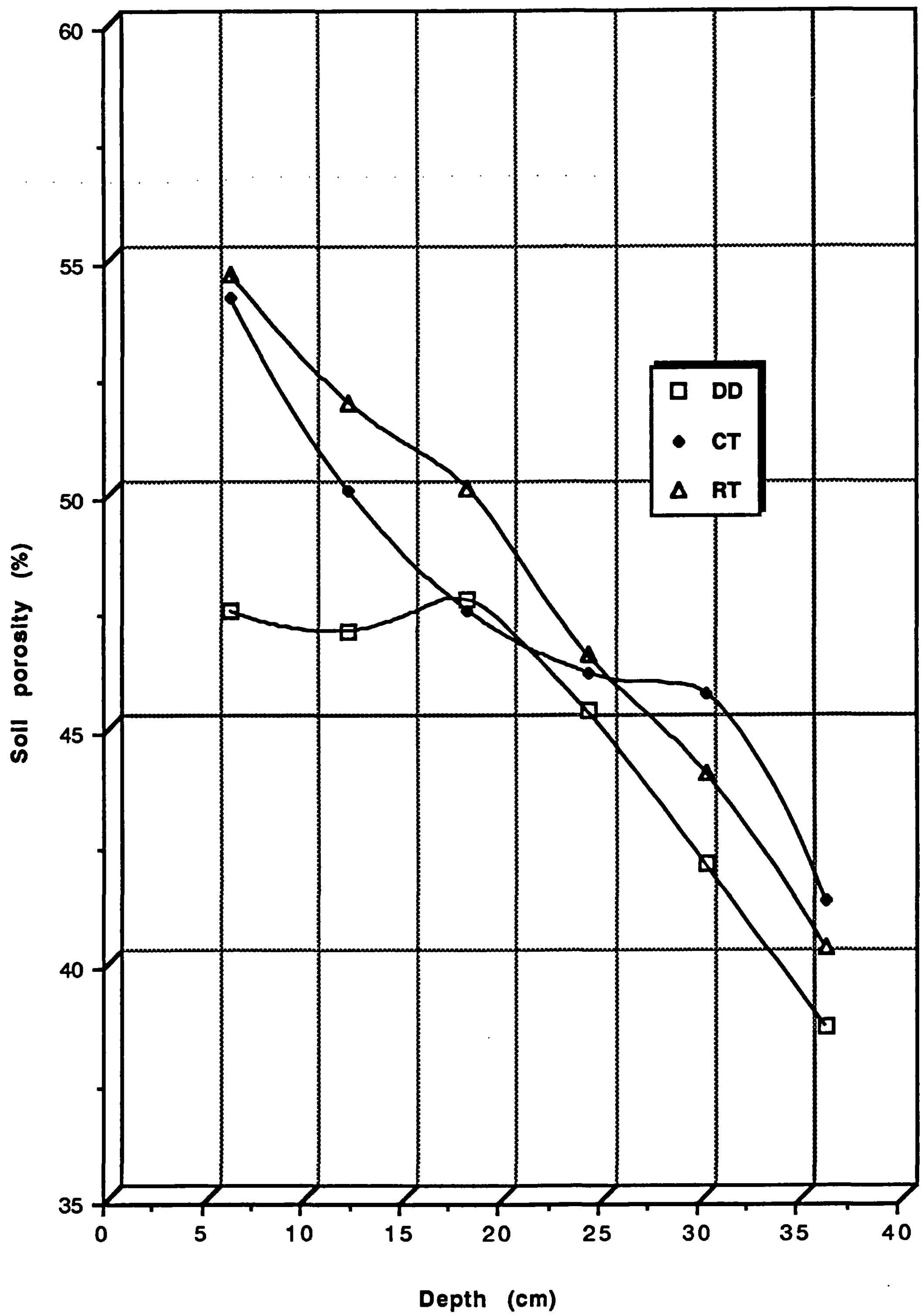


Figure 8.12 Effect on soil porosity of different tillage systems at 20 weeks after sowing.

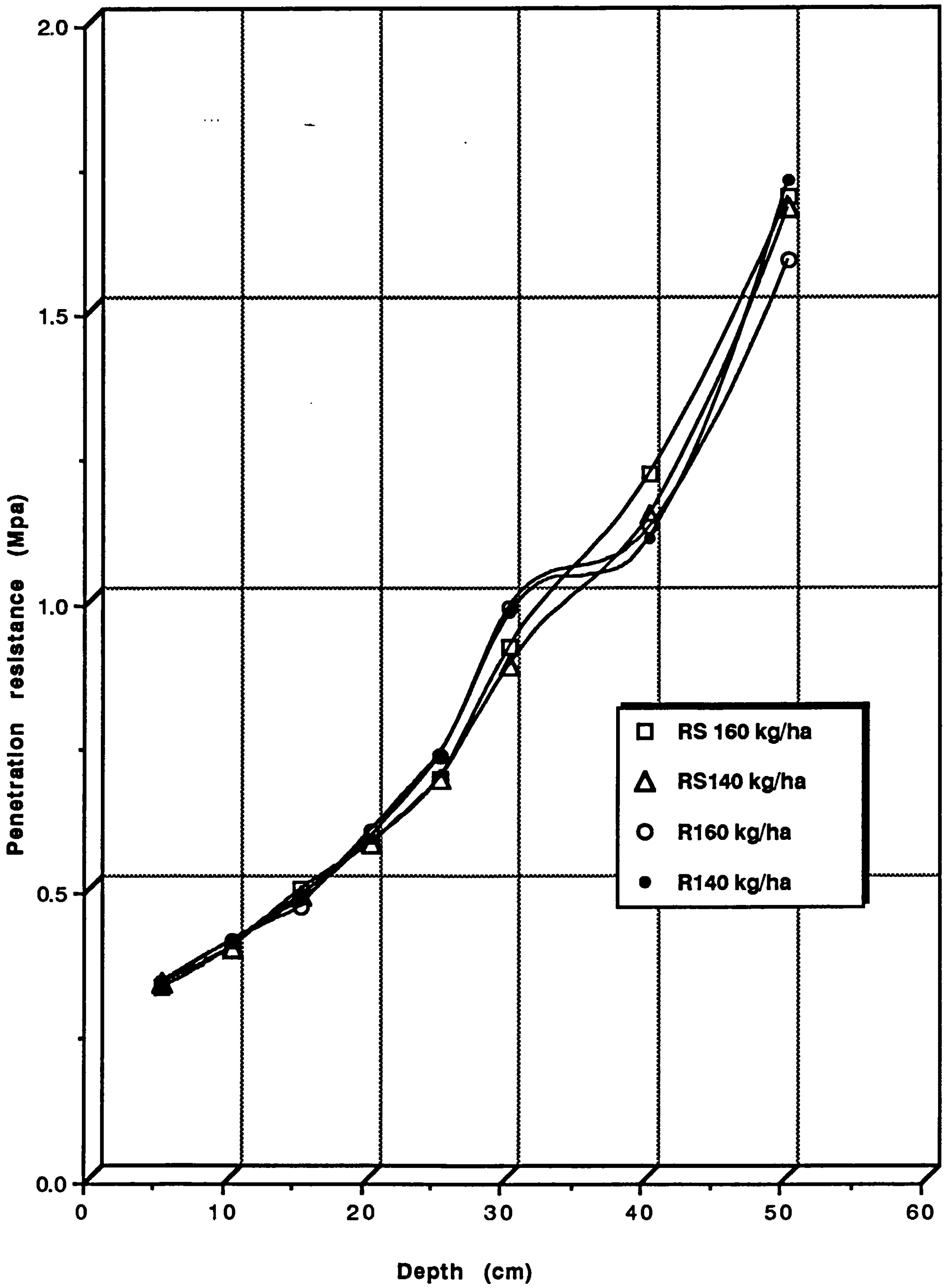


Figure 8.13 Effect on penetration resistance of Reduced Tillage practices and seed rates after the first irrigation.

Table 8.1 Effect of sowing methods and the different practices of Reduced Tillage System on penetration resistance (MPa) after the first irrigation (m.c. = 40.4%)

Sowing Method	Ridging + Ridge Splitting	Ridging
Broadcasting	0.81	0.77
Drilling	0.74	0.79

S.e.d. = 0.0129
Two factors interaction significant at P = 0.001

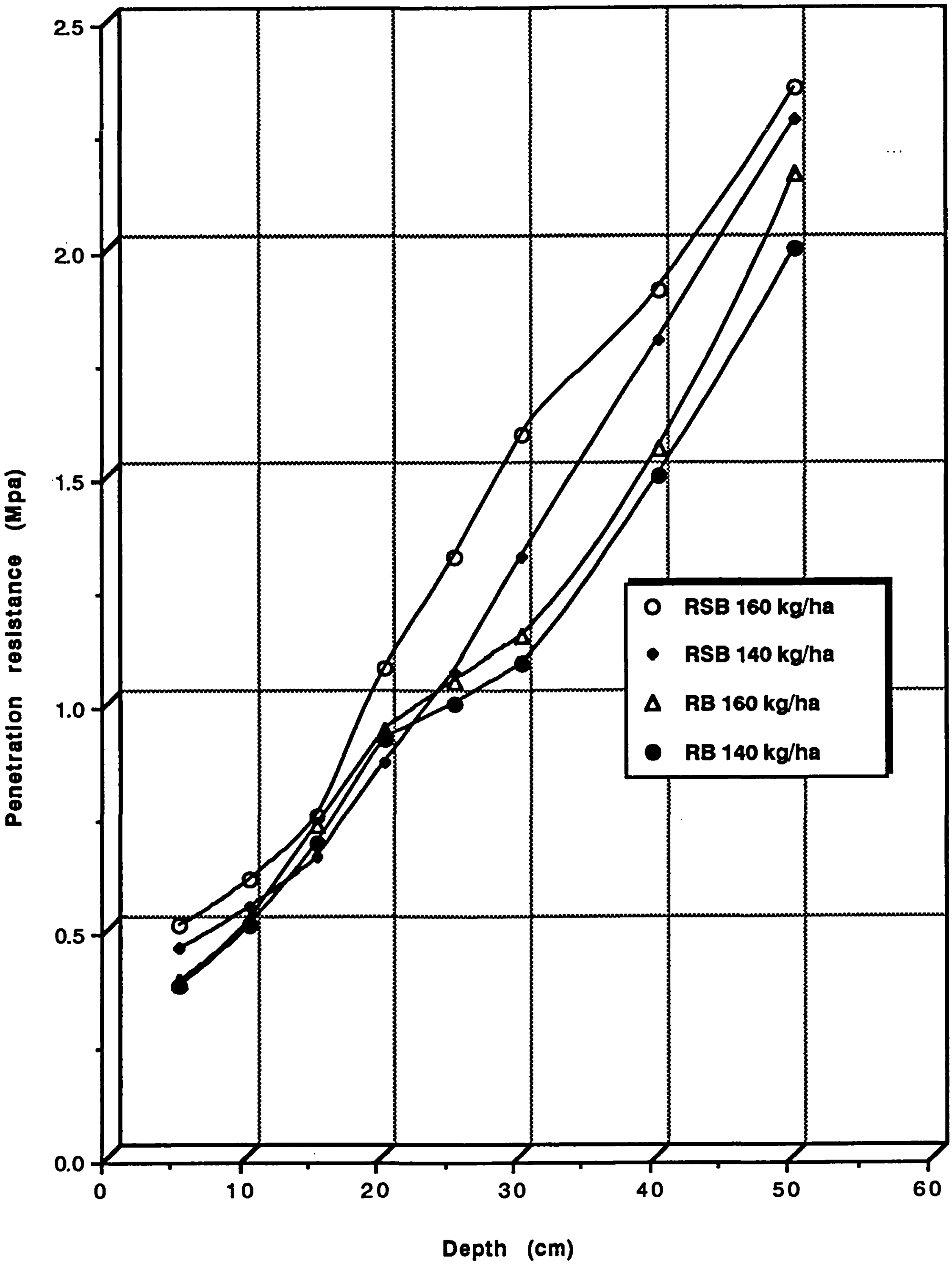


Figure 8.14 Effect on penetration resistance of Reduced Tillage practices, broadcasting and seed rates at 8 weeks after sowing.

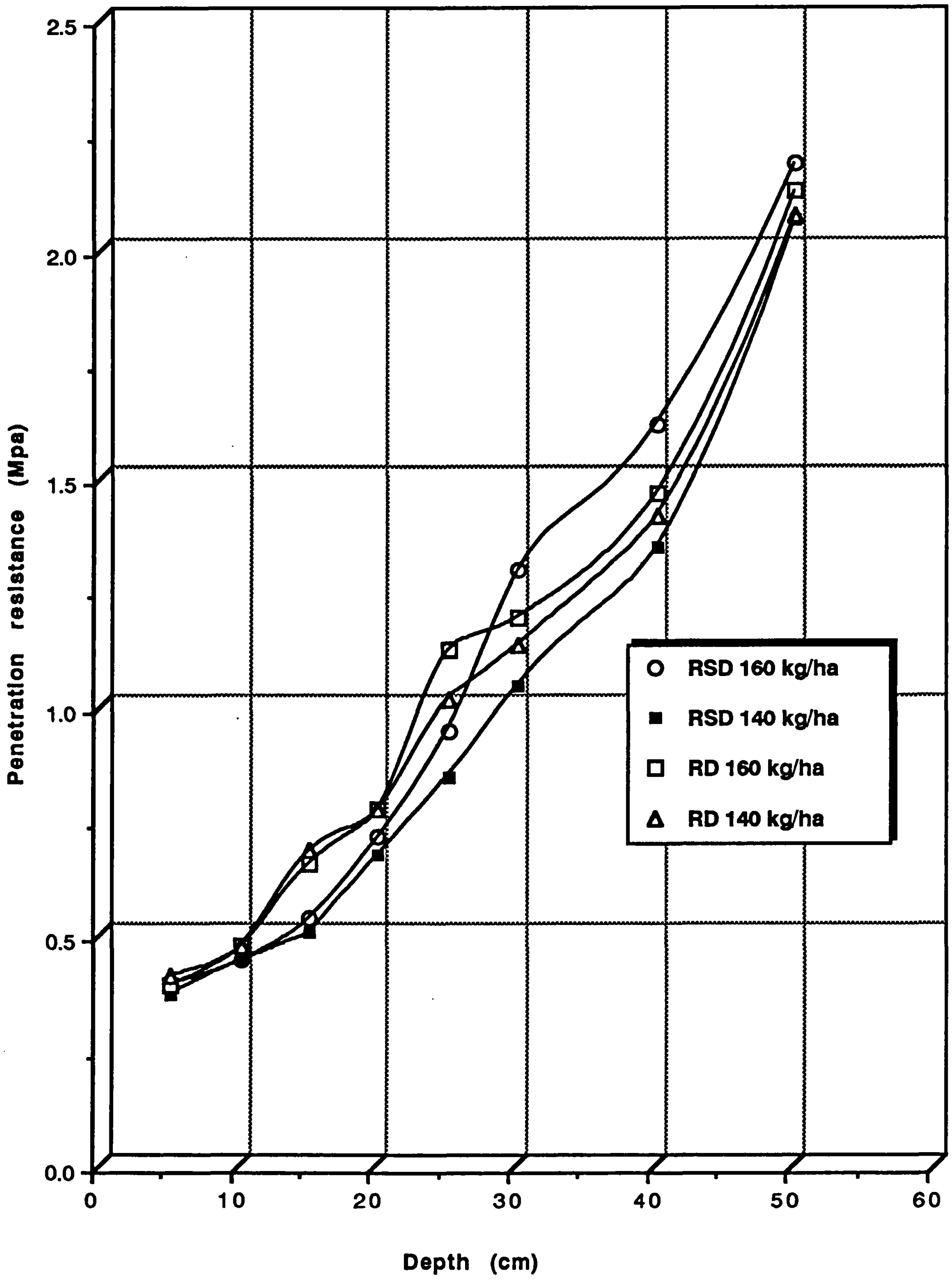


Figure 8.15 Effect on penetration resistance of Reduced Tillage practices, drilling and seed rates at 8 weeks after sowing.

At thirteen weeks after sowing, there were highly significant differences ($P<0.001$) on plots of ridging and ridge splitting practices with sowing methods (**Figure 8.16**). Penetration resistance values increased in all treatments; ridge splitting with broadcast treatment was always higher than the other treatments in penetration resistance values; all treatments at 5-25cm depth showed some differences in soil strength values.

At thirteen weeks after sowing, there were significant differences ($P<0.05$) in penetration resistance values between different treatments interaction, with the lowest value being obtained by the treatment of ridging only, with seed drilled at 140kg/ha (**Table 8.2**).

(b) EXPERIMENT 2

The effect of different tillage treatments on soil penetration resistance after the first irrigation (**Figure 8.17**) showed highly significant differences ($P<0.001$) at different depths. Direct drilling treatment showed higher resistance to penetration at all depths, followed by reduced tillage with variation in values at 25-40cm depth; conventional tillage had the lowest penetration values at all depths.

At eight weeks after sowing, there were highly significant differences ($P<0.001$) at all depths of penetration. Direct drilling again showing higher resistance to penetration at different depths, followed by reduced tillage treatment. At 20-30cm depth, reduced and conventional treatments showed differences in penetration resistance values (**Figure 8.18**).

At thirteen weeks after sowing (**Figure 8.19**) there were highly significant differences ($P<0.001$) between tillage treatments at different depths. Direct drilling treatment again showed higher resistance to penetration at all depths, but conventional tillage got closer to reduced tillage treatment in the values of penetration. However, at depths of 5-20cm, conventional and reduced tillage treatments were close in the values of resistance to penetration. Also there were significant differences ($P<0.05$) of both seed rates interaction on penetration resistance values at different depths (**Figure 8.20**). Sowing at 160kg/ha always showed higher values.

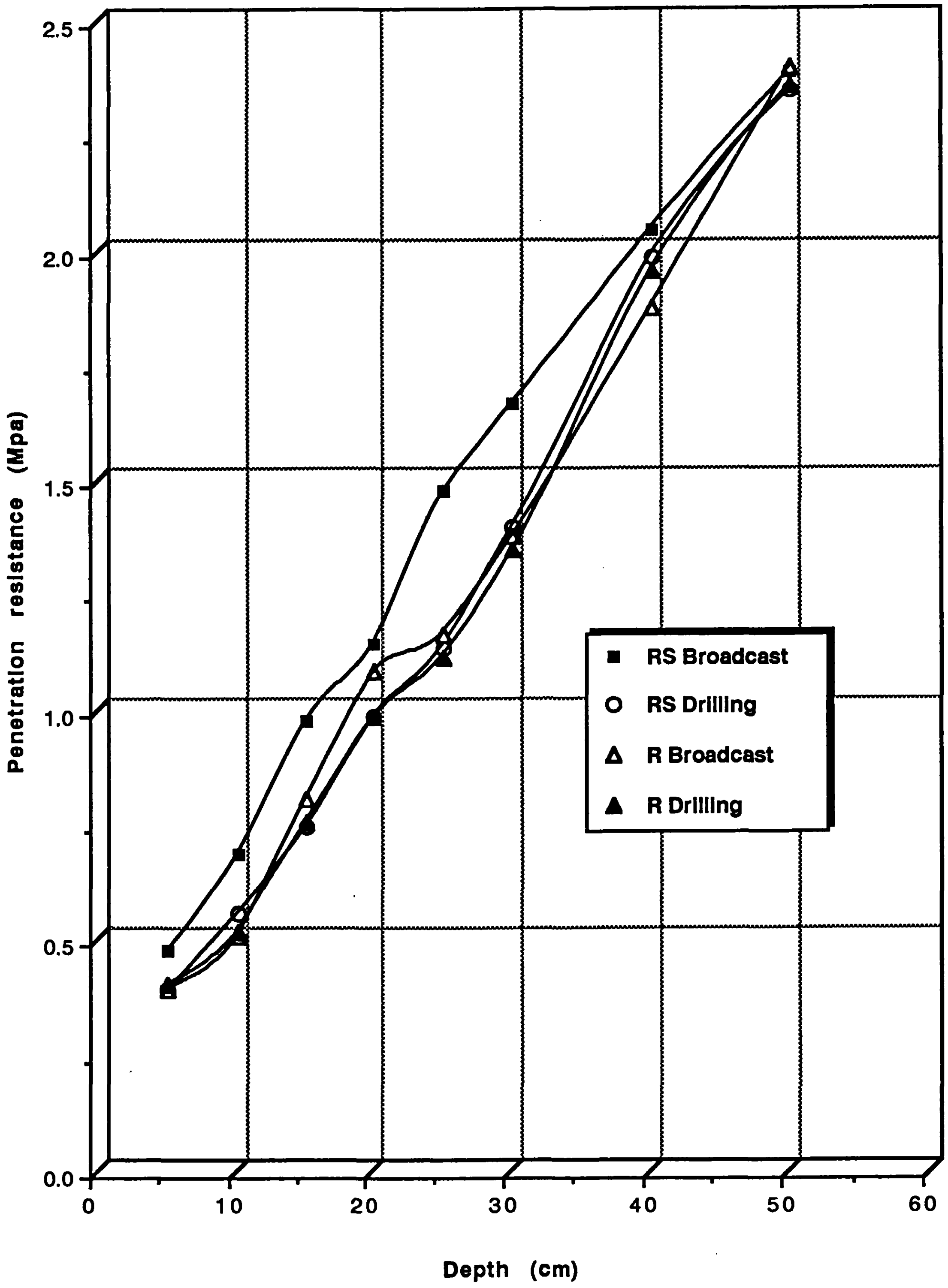


Figure 8.16 Effect on penetration resistance of Reduced Tillage practices and sowing methods at 13 weeks after sowing.

Table 8.2 Effect of sowing methods and seed rates (kg/ha) on different practices of Reduced Tillage System at 13 weeks after sowing (m.c. = 47.2%)

Treatment	Ridging + Ridge Splitting	Ridging
<u>Broadcasting</u>		
160 kg/ha	1.38	1.20
140 kg/ha	1.32	1.19
<u>Drilling</u>		
160 kg/ha	1.20	1.19
140 kg/ha	1.18	1.15

S.e.d. = 0.0127

Three factors interaction significant at P = 0.05

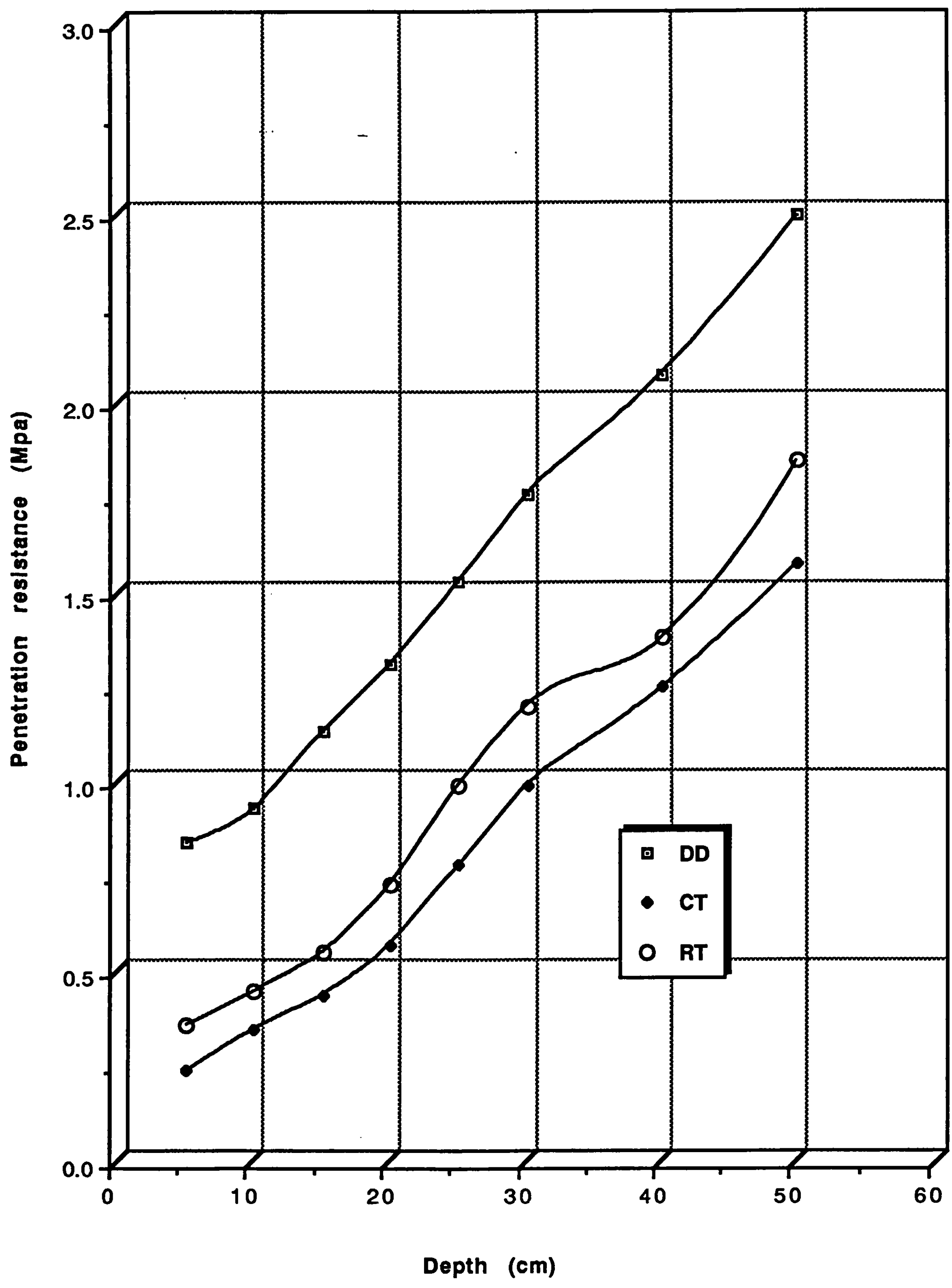


Figure 8.17 Effect on penetration resistance of different tillage systems after the first irrigation.

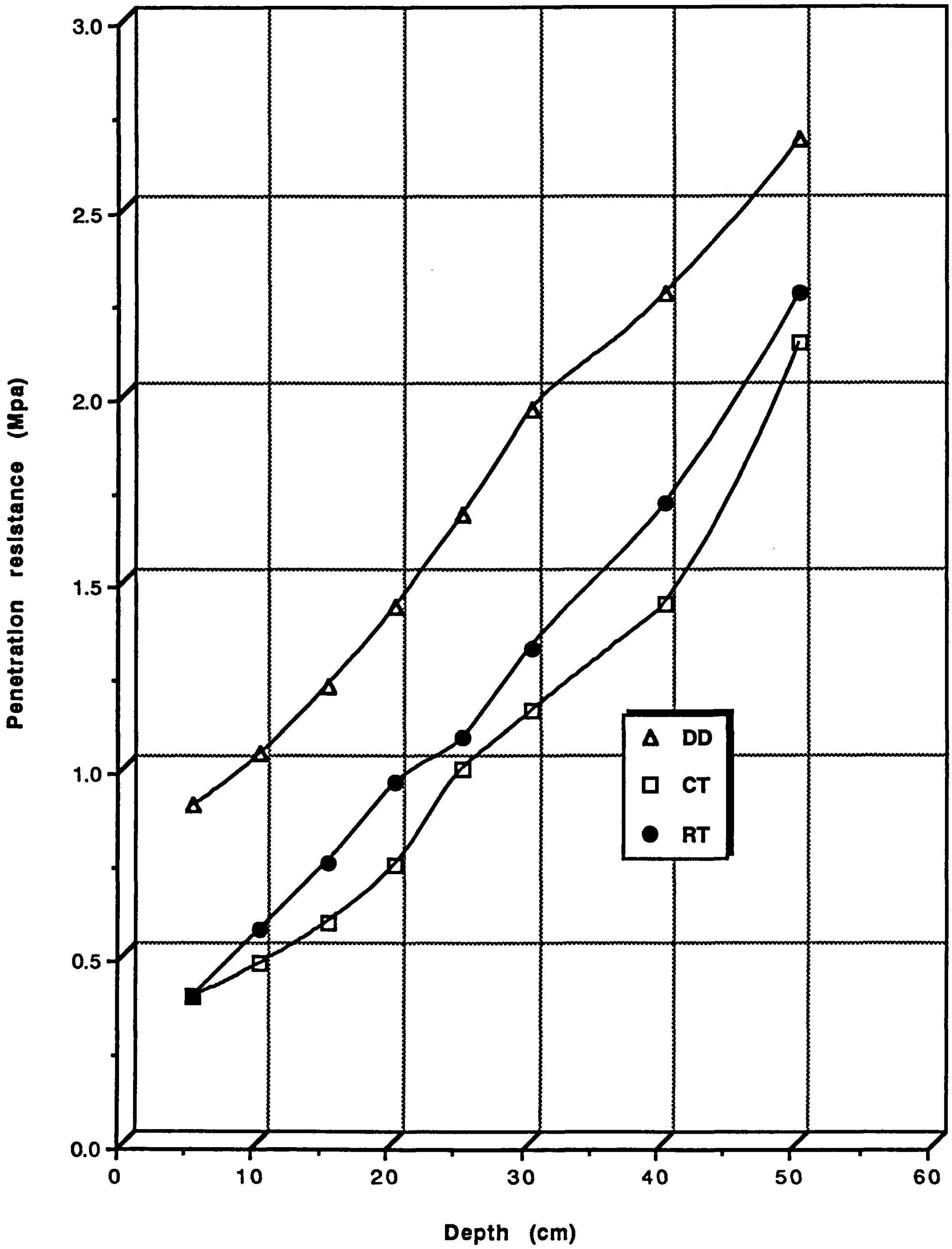


Figure 8.18 Effect on penetration resistance of different tillage systems at 8 weeks after sowing.

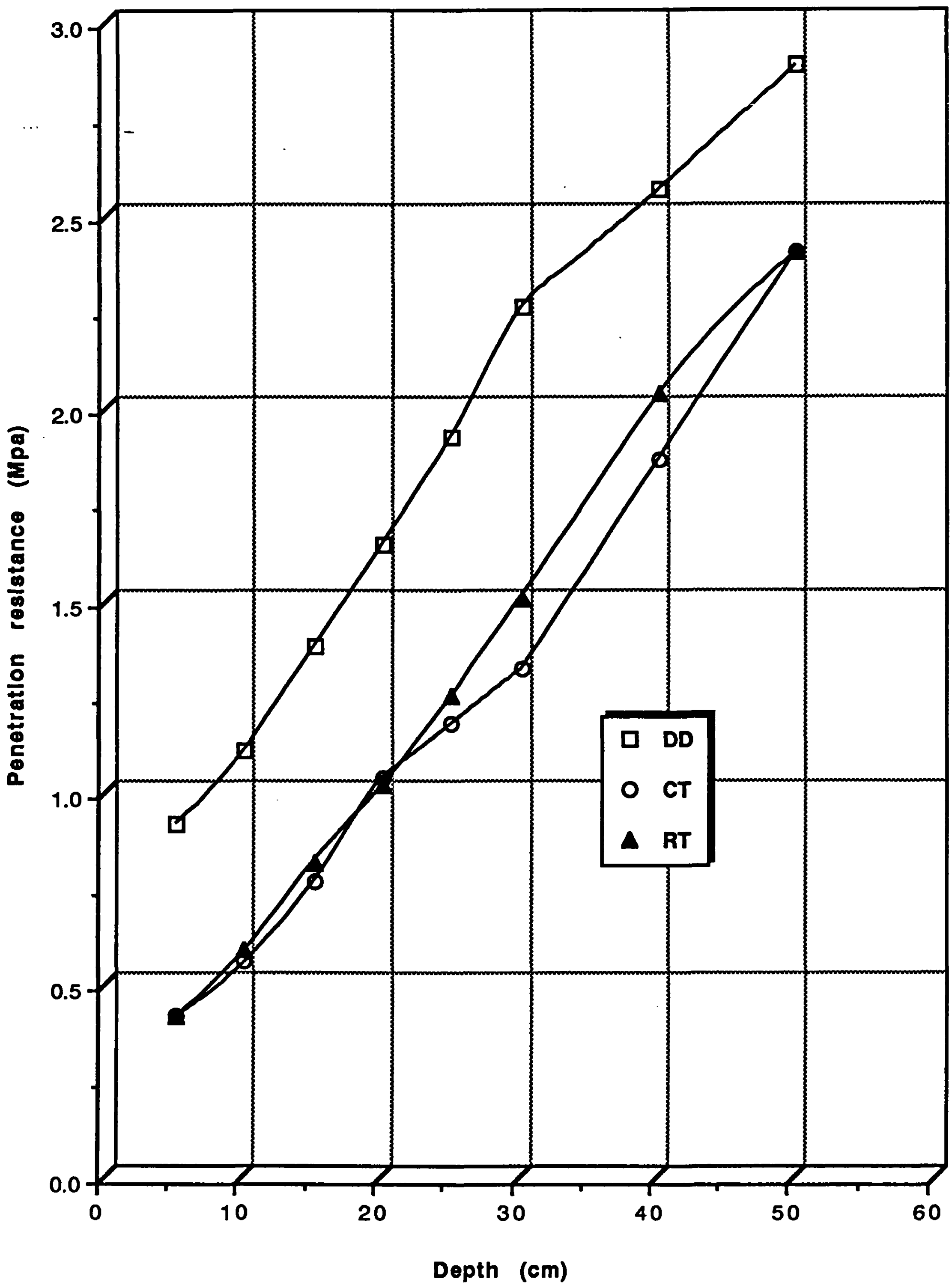


Figure 8.19 Effect on penetration resistance of different tillage systems at 13 weeks after sowing.

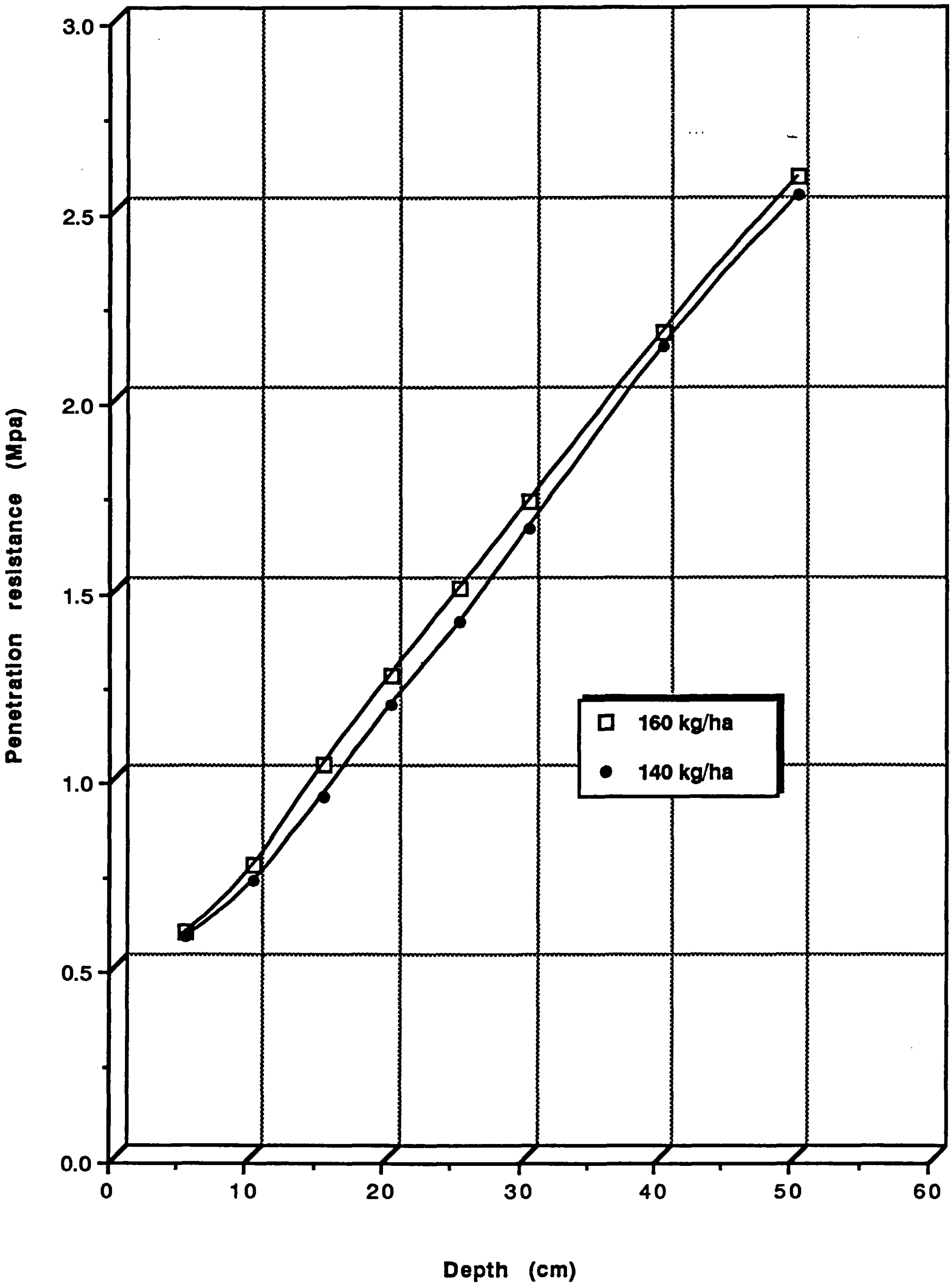


Figure 8.20 Effect on penetration resistance of different seed rates at 13 weeks after sowing.

At thirteen weeks after sowing, there were significant differences ($P<0.05$) in soil penetration resistance at different depths between tillage treatments associated with seed rates. Direct drilling treatment showed higher values with both seed rates, followed by conventional and reduced tillage with slight differences at different depths. Sowing at 160kg/ha showed higher values of penetration resistance compared with sowing at 140kg/ha (**Table 8.3**).

8.2 Plant Parameters

8.2.1 Plant Population (plants/m^2)

(a) EXPERIMENT 1

The effects of the different practices of reduced tillage and sowing methods showed significant differences on plant counts for ten weeks (**Figure 8.21**). The ridging treatment with broadcast seed always had the highest value of plants/m^2. Eight weeks after sowing, plants/m^2 reduced slightly (about 10 plants/m^2).

Table 8.4 shows the significant differences of sowing methods and seed rates interaction on plants/m^2 at the first week after sowing. Results showed very slight differences between sowing methods at the lower seed rate (140kg/ha): a higher value was obtained with broadcast treatment, but this was only in the first week after sowing when not all seeds were germinated.

In the second week after sowing (**Table 8.5**), there was a significant interaction between sowing methods and seed rates on plants/m^2. Broadcast treatment at the lower seed rate had a higher value (199.8) followed by the same treatment with a higher seed rate (160kg/ha).

In the third week after sowing (**Table 8.6**), there was a significant interaction between reduced tillage practices, sowing methods and seed rates on plants/m^2. The ridging treatment with lower seed rate had higher values with both sowing methods.

Table 8.3 Effect on Penetration Resistance (MPa) of different tillage systems and seed rates (kg/ha) at 13 weeks after sowing (m.c. = 47.2%)

Treatment	Penetration Depth (cm)							
	5	10	15	20	25	30	40	50
DD								
160 kg/ha	0.92	1.13	1.40	1.70	2.00	2.32	2.59	2.92
140 kg/ha	0.90	1.06	1.34	1.57	1.84	2.19	2.53	2.84
CT								
160 kg/ha	0.41	0.56	0.77	1.04	1.19	1.32	1.86	2.41
140 kg/ha	0.40	0.53	0.74	1.01	1.15	1.29	1.86	2.38
RT								
160 kg/ha	0.42	0.58	0.88	1.04	1.28	1.51	2.05	2.42
140 kg/ha	0.40	0.58	0.74	0.97	1.20	1.48	2.00	2.37

S.e.d. = 0.0152
Three factors interaction significant at $P = 0.05$

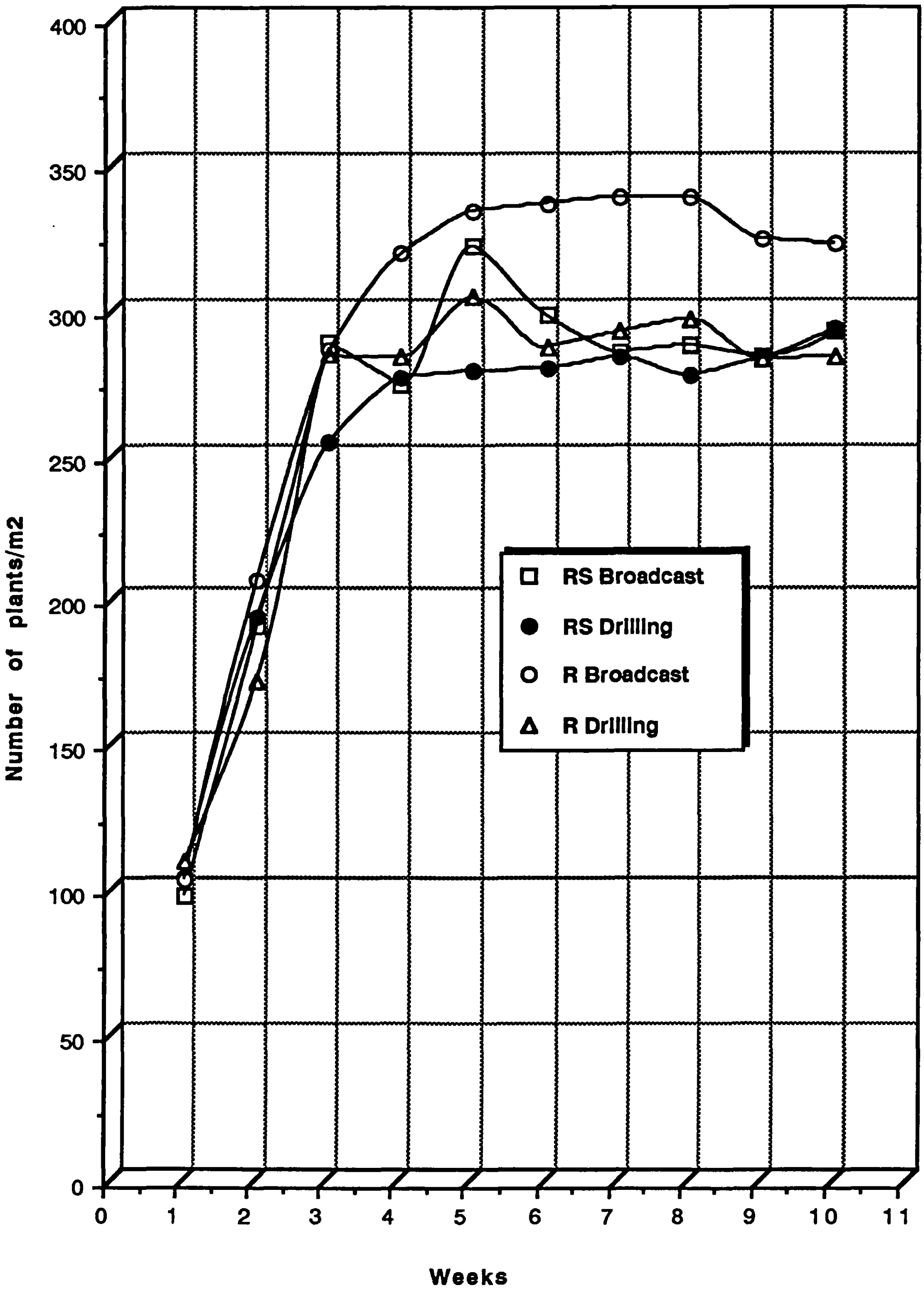


Figure 8.21 Effect of Reduced Tillage practices and sowing methods on number of plants per square metre for 10 weeks after sowing.

Table 8.4 Effect of sowing methods and seed rates (kg/ha) on number of plants per square metre at the first week after sowing.

Sowing Method	Seed rate (kg/ha)	
	160	140
Broadcasting	93.2	105.9
Drilling	107.5	105.0

S.e.d. = 3.82
Two factors interaction significant at P = 0.01

Table 8.5 Effect of sowing methods and seed rates (kg/ha) on number of plants per square metre at the second week after sowing

Sowing Method	Seed rate (kg/ha)	
	160	140
Broadcasting	195.7	199.8
Drilling	187.9	176.3

S.e.d. = 5.08
Two factors interaction significant at P = 0.05

Table 8.6 Effect of different practices of Reduced Tillage System, sowing methods and seed rate (kg/ha) on number of plants per square metre at the third week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge splitting		
Broadcasting	288.2	286.8
Drilling	273.9	233.9
Ridging		
Broadcasting	278.2	292.1
Drilling	274.6	292.5

S.e.d. = 8.52
Three factors interaction significant at P = 0.05

(b) EXPERIMENT 2

Figure 8.22 shows the mean effects of different tillage systems compared with the reduced tillage system (ridging only with seed broadcast at 140kg/ha) on plants/m^2 for ten weeks. Reduced tillage always showed higher values of plants/m^2 during the period of measurement, compared with direct drilling and conventional tillage, the values for which were variable during the ten week measurement period, but always lower (less than 300 plants/m^2).

After the fifth week of sowing, reduced tillage showed a slight reduction in plants/m^2 (about 15 plants/m^2) while the maximum level of plant stand was 349 plants/m^2.

There were significant differences in plants/m^2 between the two seed rates, the lower seed rate resulting in the highest value (**Table 8.7**).

8.2.2 Leaf and Tiller Development

8.2.2.1 Number of Leaves per Main Stem of Plant

(a) EXPERIMENT 1

Reduced tillage practices showed only slight variations in the number of leaves per main stem during the twelve weeks after sowing (**Figure 8.23**). Both seed rates showed only slight variation during the test period (**Figure 8.24**). The plants had an average of five leaves, which is typical of the variety of wheat (Achtar G2). After the fourth week from sowing (**Table 8.8**) there was, however, a significant interaction between reduced tillage practices, sowing methods and seed rates. Seed broadcast at 140kg/ha generally showed higher values in the number of leaves per main stem of plant, the highest value being obtained with ridge splitting.

At the seventh week after sowing, the mean effect of sowing methods showed only slight variation between treatments (**Table 8.9**).

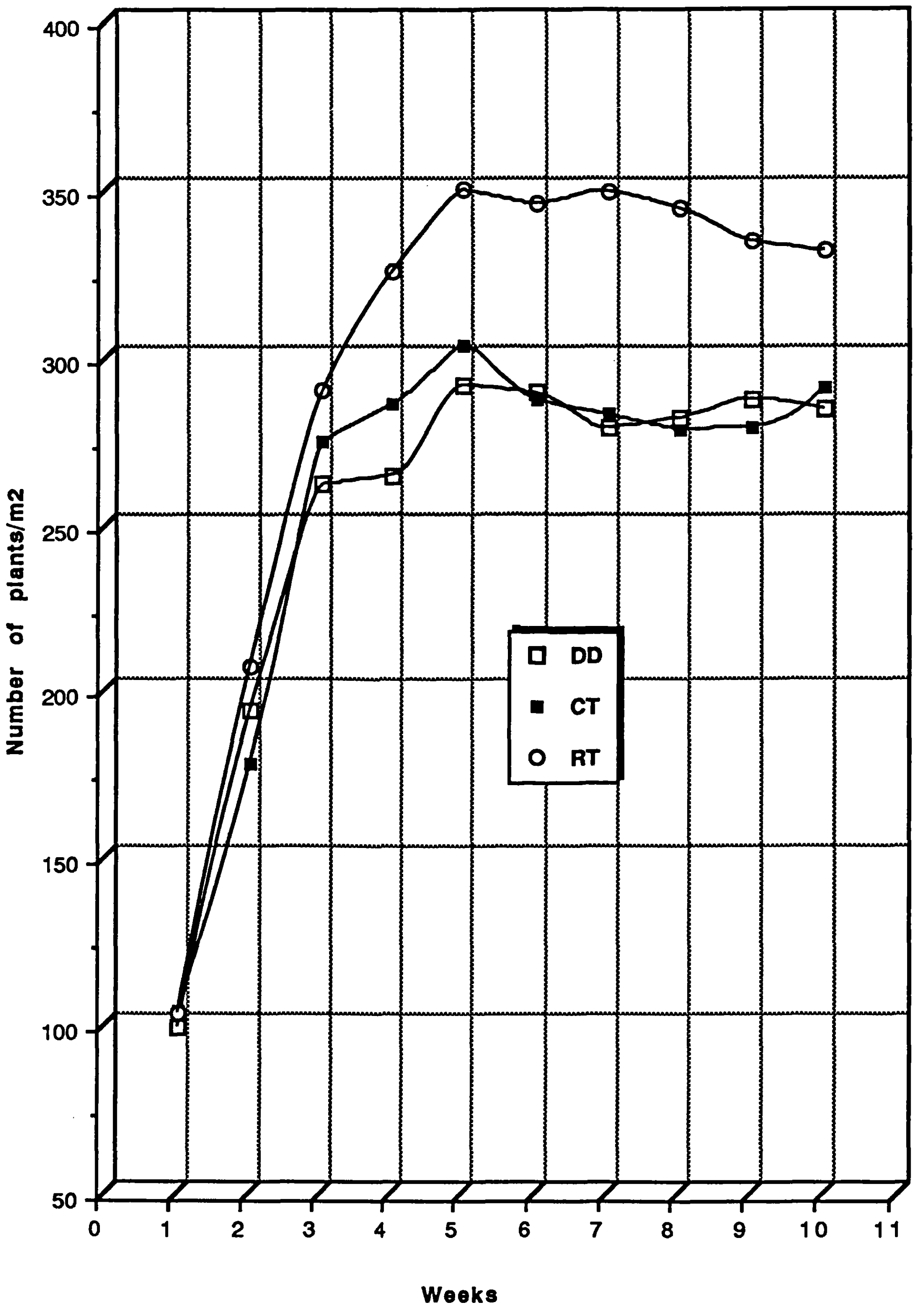


Figure 8.22 Mean effect of different tillage systems on number of plants per square metre for 10 weeks after sowing.

Table 8.7 Mean effect of seed rate (kg/ha) on number of plants per square metre at the fourth week after sowing.

Seed rate (kg/ha)	
160	140
284.0	298.7

S.e.d. = 5.68
Significant at P = 0.05

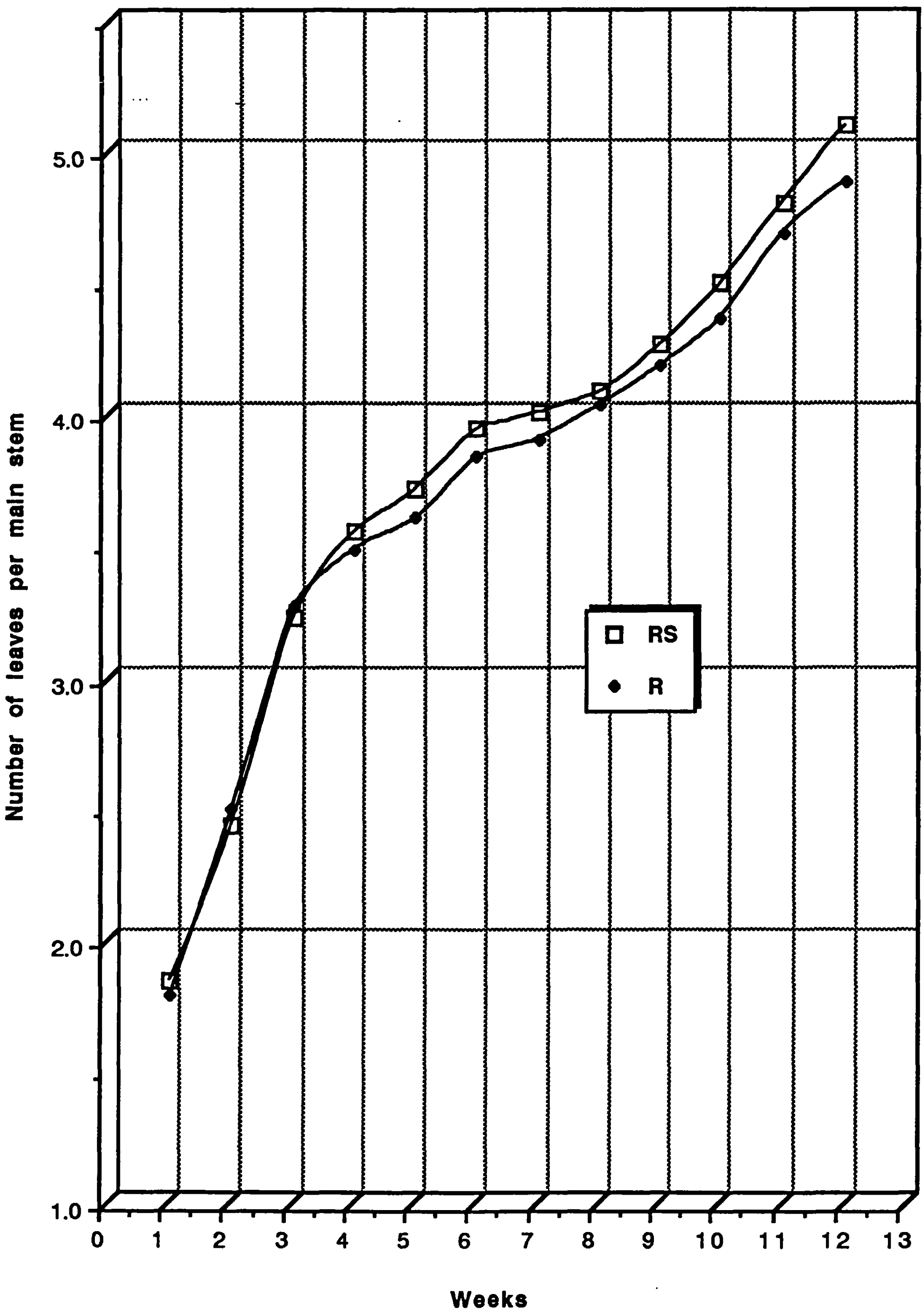


Figure 8.23 Effect of Reduced Tillage practices on number of leaves per main stem of plant for 12 weeks after sowing.

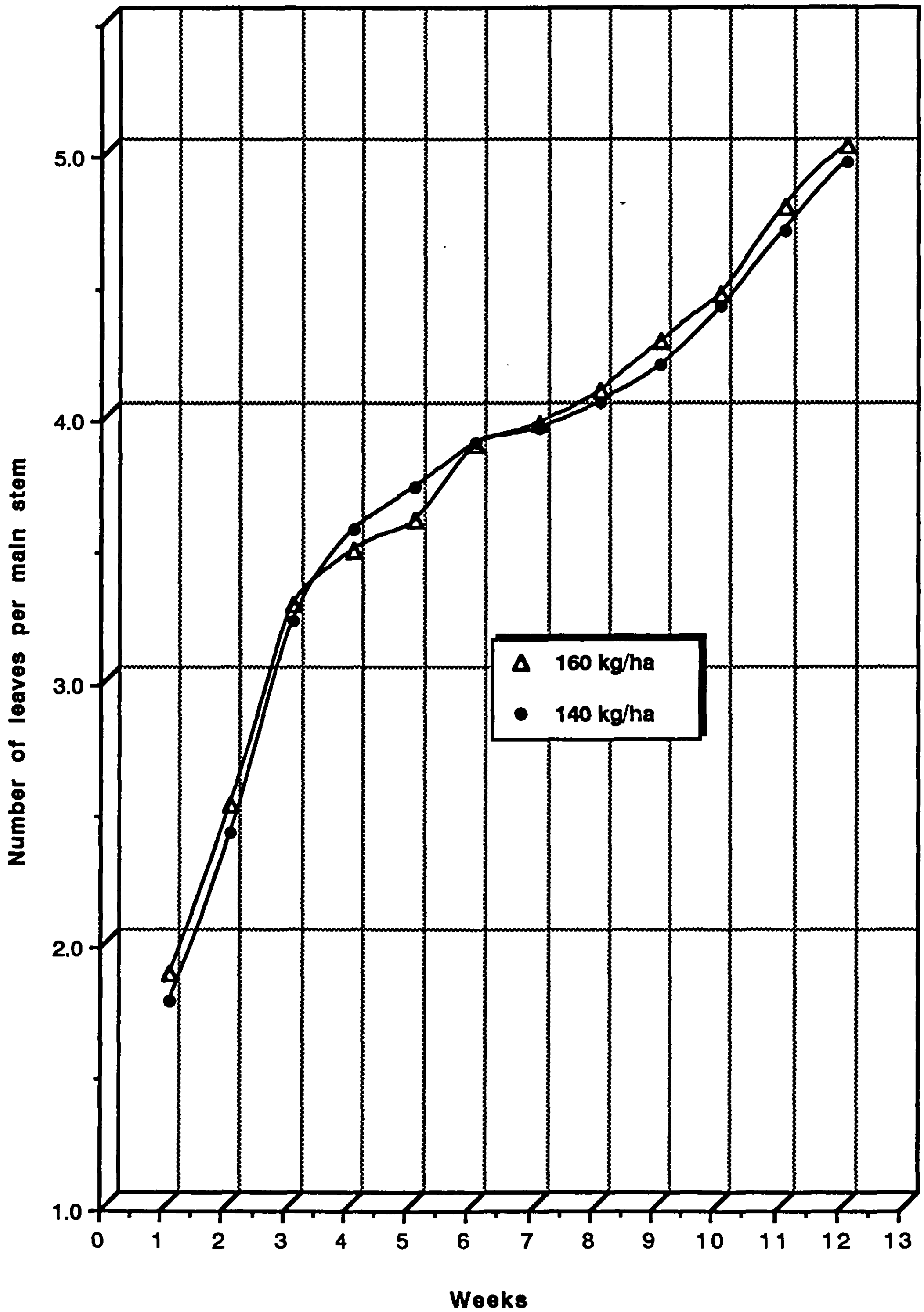


Figure 8.24 Effect of seed rates on number of leaves per main stem of plant for 12 weeks after sowing.

Table 8.8 Effect of different practices of Reduced Tillage System, sowing methods and seed rates (kg/ha) on number of leaves per main stem of plant at the fourth week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge Splitting		
Broadcasting	3.43	3.63
Drilling	3.58	3.58
Ridging		
Broadcasting	3.53	3.50
Drilling	3.38	3.53

S.e.d. = 0.0878
Three factors interaction significant at P = 0.05

Table 8.9 Mean effect of sowing methods on number of leaves per main stem of plant at the seventh week after sowing.

Broadcasting	Drilling
3.91	3.99

S.e.d. = 0.0417
Significant at P = 0.05

At the ninth week after sowing (**Table 8.10**), there was a significant interaction between sowing methods and seed rates. Seed broadcast at the high seed rate showed higher values in the number of leaves per main stem of plant compared with drilling. However, seed drilled at the lower seed rate showed a higher value compared with broadcasting.

(b) EXPERIMENT 2

At twelve weeks after sowing, there were significant differences in the mean effects of different tillage systems and seed rates on the total number of leaves per main stem of plant. The range was variable within different treatments at different seed rates (**Figure 8.25**).

8.2.2.2 Total Number of Stems per Plant

(a) EXPERIMENT 1

Sowing at 160kg/ha resulted in more stems per plant compared with sowing at 140kg/ha in both weeks 4 and 5 (**Tables 8.11 and 8.12**).

By the tenth, eleventh and twelfth weeks after sowing, there was significant interaction in the total number of stems per plant between reduced tillage practices, sowing methods and seed rates. Results showed that the ridging treatment with seed drilled at the lower seed rate always had a higher value compared with broadcasting. The opposite was true when the ridge splitting technique was used (**Tables 8.13, 8.14 and 8.15**).

(b) EXPERIMENT 2

The effect of different tillage systems showed significant differences (**Figure 8.26**) on the total number of stems per plant. Reduced tillage always had a higher value between seven and ten weeks after sowing, the values stabilizing after the tenth week. Conventional tillage showed the next level of values, with direct drilling stabilizing slightly lower.

Table 8.10 Effect of sowing methods and seed rates (kg/ha) on number of leaves per main stem of plant at the ninth week after sowing.

Sowing Method	Seed rate (kg/ha)	
	160	140
Broadcasting	4.33	4.13
Drilling	4.21	4.23

S.e.d. = 0.0599
Two factors interaction significant at P = 0.05

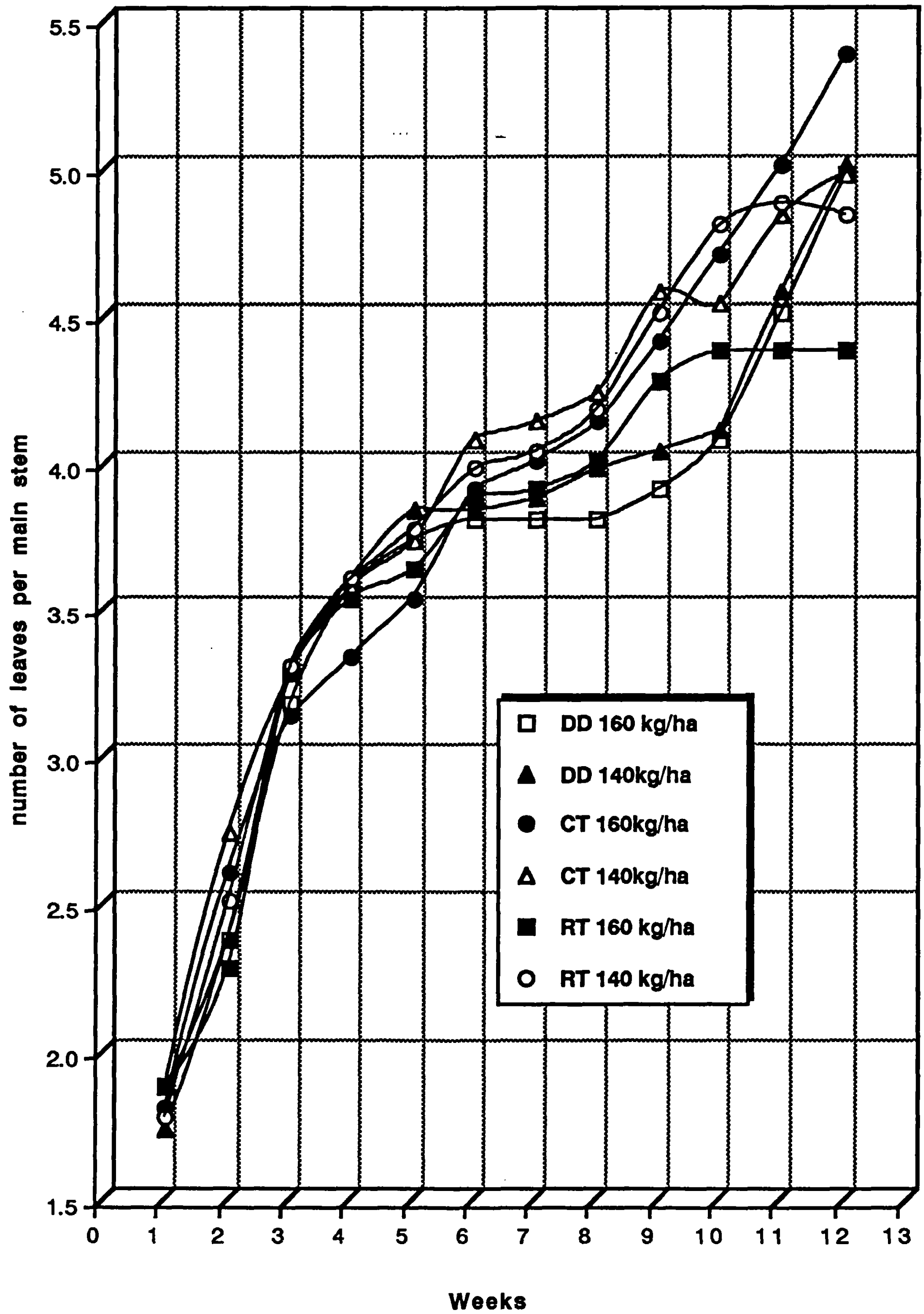


Figure 8.25 Mean effect of different tillage systems and seed rates on total number of leaves per main stem of plant for 12 weeks after sowing.

Table 8.11 Mean effect of seed rate (kg/ha) on total number of stems per plant at the fourth week after sowing

Seed rate (kg/ha)	
160	140
1.31	1.18

S.e.d. = 0.0576
Significant at P = 0.05

Table 8.12 Mean effect of seed rate (kg/ha) on total number of stems per plant at the fifth week after sowing.

Seed rate (kg/ha)	
160	140
2.04	1.80

S.e.d. = 0.1104
Significant at P = 0.05

Table 8.13 Effect of different practices of Reduced Tillage System, sowing methods and seed rates (kg/ha) on total number of stems per plant at the tenth week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge Splitting		
Broadcasting	3.70	3.90
Drilling	3.93	3.48
Ridging		
Broadcasting	3.95	3.73
Drilling	3.65	4.03

S.e.d. = 0.2627
Three factors interaction significant at P = 0.05

Table 8.14 Effect of different practices of Reduced Tillage System, sowing methods and seed rates (kg/ha) on total number of stems per plant at the eleventh week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge Splitting		
Broadcasting	3.68	3.90
Drilling	3.93	3.48
Ridging		
Broadcasting	3.95	3.73
Drilling	3.65	4.03

S.e.d. = 0.2631
Three factors interaction significant at P = 0.05

Table 8.15 Effect of different practices of Reduced Tillage System, sowing methods and seed rates (kg/ha) on total number of stems per plant at the twelfth week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge Splitting		
Broadcasting	3.68	3.80
Drilling	3.93	3.48
Ridging		
Broadcasting	3.98	3.80
Drilling	3.60	4.03

S.e.d. = 0.2664

Three factors interaction significant at P = 0.05

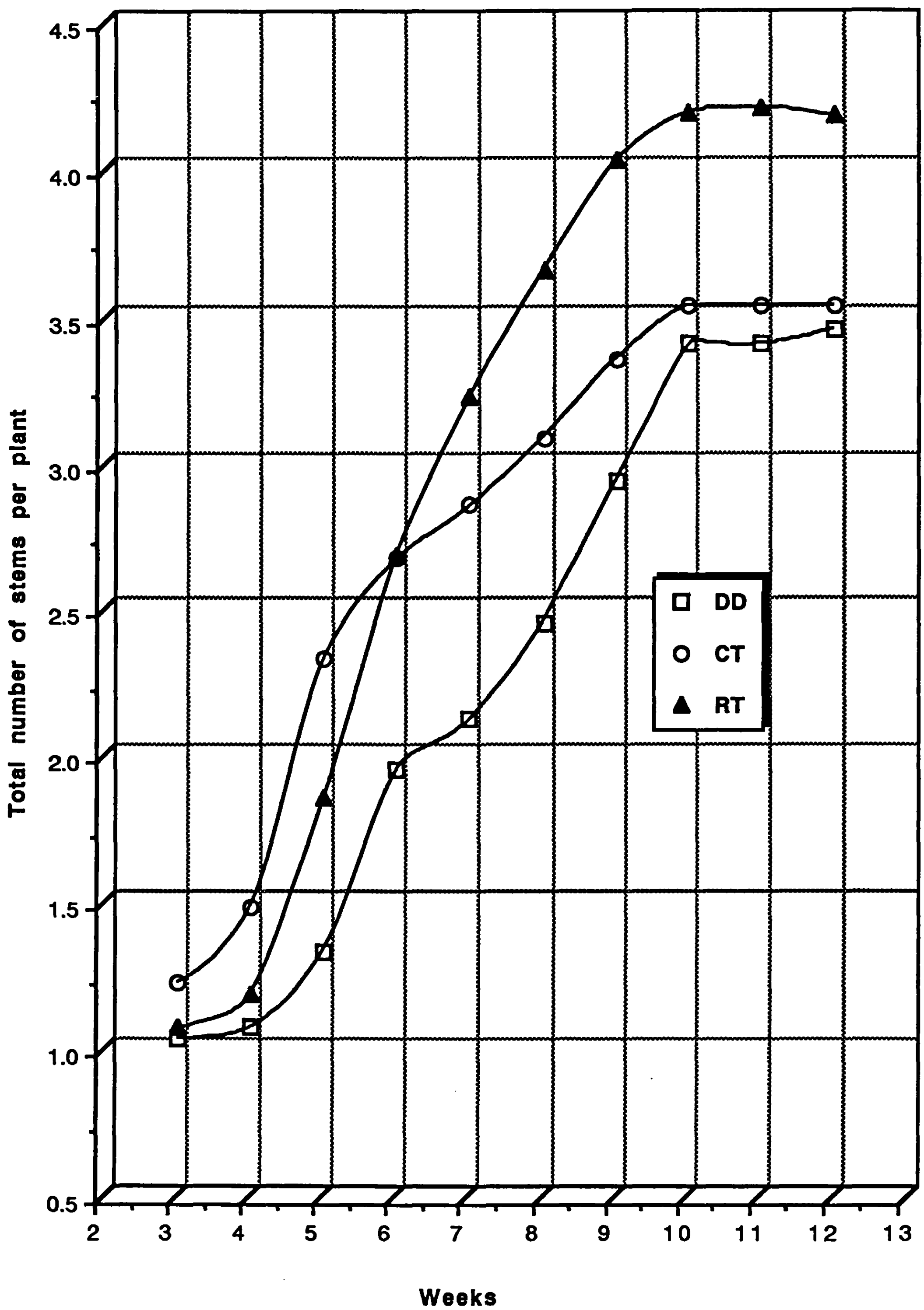


Figure 8.26 Mean effect of different tillage systems on total number of stems per plant for 12 weeks after sowing.

8.2.2.3 Total Number of Leaves per Plant

(a) EXPERIMENT 1

The results of the different practices of reduced tillage on the total number of leaves per plant at the third week after sowing (**Table 8.16**) showed that ridging had a higher value compared with the ridge splitting treatment. Sowing at the higher seed rate also increased leaf numbers per plant (**Table 8.17**).

(b) EXPERIMENT 2

The effect of the different tillage systems during the twelve weeks after sowing (**Figure 8.27**) showed that the reduced tillage plots developed an average of 27 leaves per plant. Plants grown from conventional tillage produced 20 leaves per plant and with direct drilling, the figure was 17 leaves per plant.

8.2.2.4 Number of Leaves per Stem of Plant

(a) EXPERIMENT 1

The mean effect of seed rate during the fourth and fifth weeks after sowing (**Tables 8.18 and 8.19**) on the number of leaves per stem of plant, showed that higher values were obtained with a lower seed rate on both occasions. However, at the tenth week after sowing (**Table 8.20**), there were significant differences for the effect of different practices of reduced tillage, sowing methods and seed rates.

The highest value was obtained with ridge splitting and seed broadcast at 160kg/ha. Ridging with seed broadcast at 140kg/ha showed a lower value.

(b) EXPERIMENT 2

The mean effect of different tillage systems at twelve weeks showed that reduced tillage had a higher value on the total number of leaves per stem compared with conventional tillage and direct drilling (**Figure 8.28**).

Table 8.16 Mean effect of different practices of Reduced Tillage System on total number of leaves per plant at the third week after sowing.

Ridging + Ridge Splitting	Ridging
3.38	3.54

S.e.d. = 0.0740
Significant at P = 0.05

Table 8.17 Mean effect of seed rate (kg/ha) on total number of leaves per plant at the third week after sowing.

Seed rate (kg/ha)	
160	140
3.54	3.38

S.e.d. = 0.0740
Significant at P = 0.05

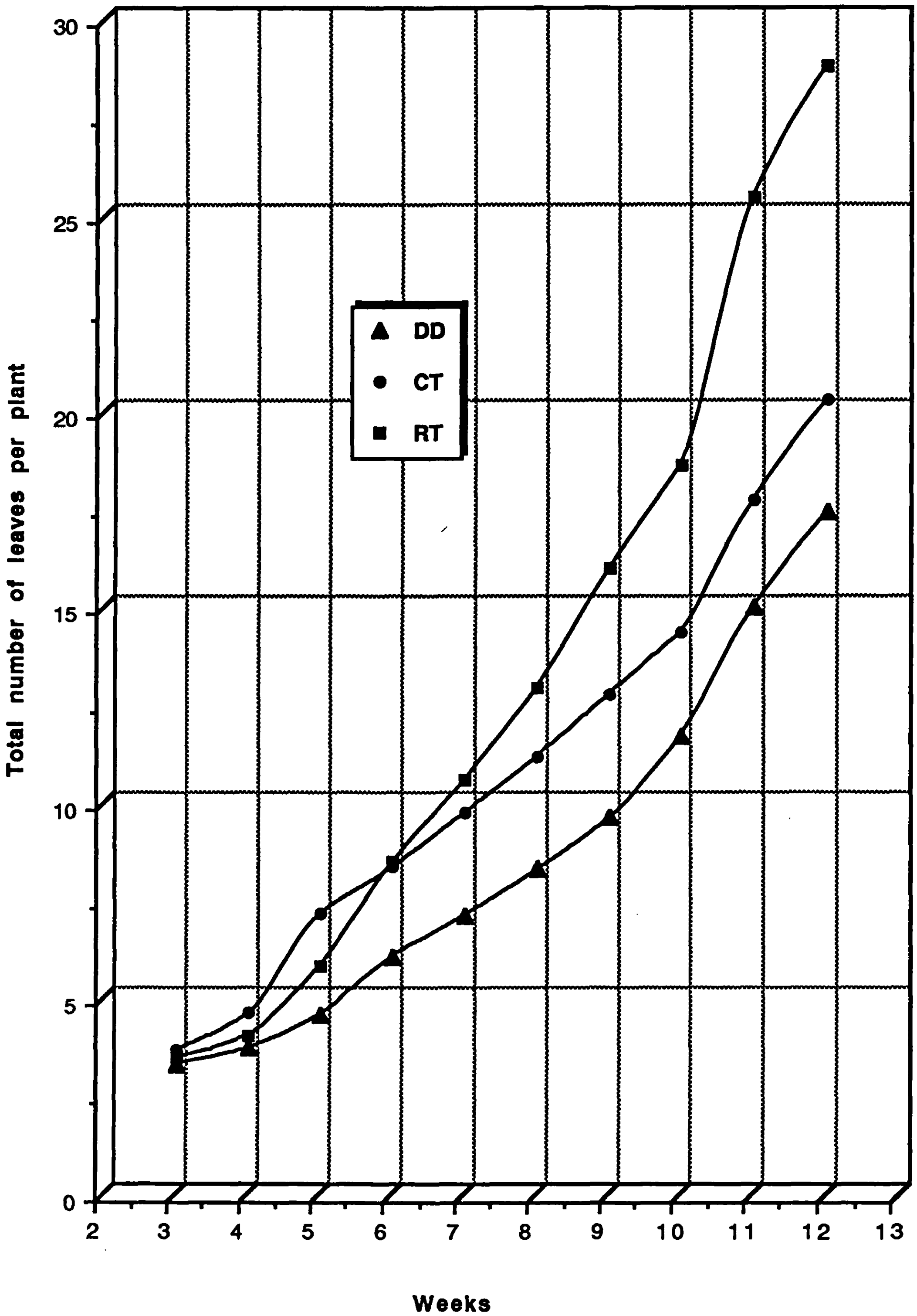


Figure 8.27 Mean effect of different tillage systems on total number of leaves per plant for 12 weeks after sowing.

Table 8.18 Mean effect of seed rate (kg/ha) on number of leaves per stem of plant at the fourth week after sowing.

Seed rate (kg/ha)	
160	140
3.33	3.48

S.e.d. = 0.0595
Significant at P = 0.05

Table 8.19 Mean effect of seed rate (kg/ha) on number of leaves per stem of plant at the fifth week after sowing.

Seed rate (kg/ha)	
160	140
3.24	3.41

S.e.d. = 0.0646
Significant at P = 0.05

Table 8.20 Effect of different practices of Reduced Tillage System, sowing methods and seed rates (kg/ha) on number of leaves per stem of plant at the tenth week after sowing.

Treatment	Seed rate (kg/ha)	
	160	140
Ridging + Ridge Splitting		
Broadcasting	4.15	3.92
Drilling	3.86	4.12
Ridging		
Broadcasting	3.97	4.09
Drilling	4.02	4.03

S.e.d. = 0.1406

Three factors interaction significant at P = 0.05

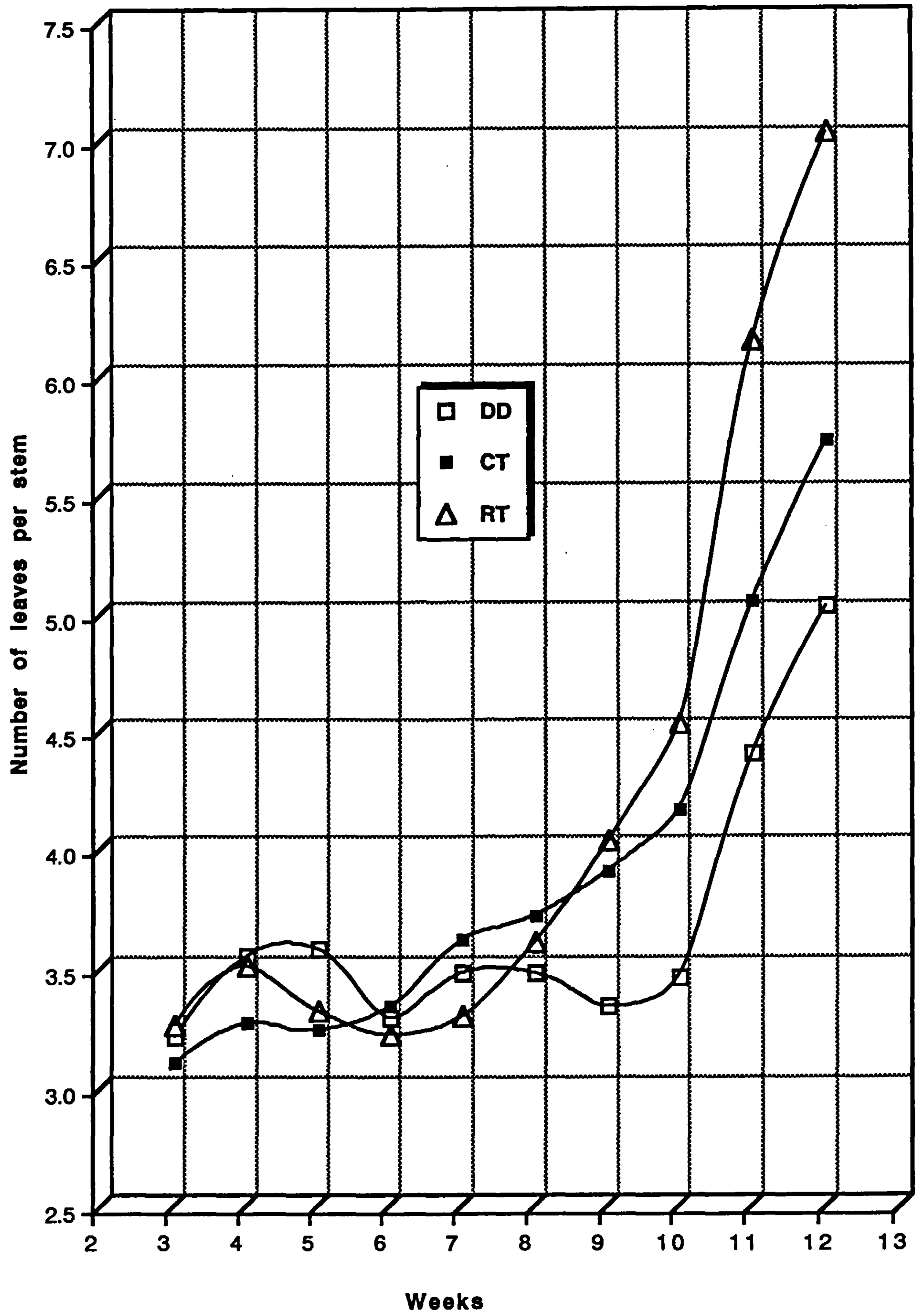


Figure 8.28 Mean effect of different tillage systems on number of leaves per stem of plant for 12 weeks after sowing.

8.2.3 Yield and Components

8.2.3.1 Weight of Grain per Ear (wt/ear)

(a) EXPERIMENT 1

The mean effect of different practices of reduced tillage on the weight of grain per ear was slight (**Table 8.21**). However, sowing methods interacted with seed rate. At the higher seed rate, broadcast gave the highest value, but at the lower seed rate, direct drilling was best (**Table 8.22**).

8.2.3.2 Number of Ears per Square Metre (ears/m^2)

(b) EXPERIMENT 2

The mean effect on number of ears/m^2 of different tillage systems showed significant differences. Reduced tillage showed the highest value, followed by direct drilling. The conventional system showed the lowest value (**Table 8.23**).

8.2.3.3 Yield (kg/ha)

(a) EXPERIMENT 1

Sowing methods interacted with seed rate on grain yield (**Table 8.24**). Highest yields were obtained from drilling at 140kg/ha followed by broadcasting at 160kg/ha.

(b) EXPERIMENT 2

The effect on grain yield of different tillage systems and seed rates showed significant differences (**Table 8.25**). Reduced tillage (ridging only) at the lower seed rate gave considerably better grain yield compared with the other treatments.

Table 8.21 Mean effect of different practices of Reduced Tillage System on weight of grain per ear (g).

Ridging + Ridge Splitting	Ridging
0.26	0.25

S.e.d. = 0.0060
Significant at P = 0.05

Table 8.22 Effect on weight of grain per ear (g) of different sowing methods and seed rates (kg/ha).

Sowing Method	Seed rate (kg/ha)	
	160	140
Broadcasting	0.26	0.24
Drilling	0.24	0.27

S.e.d. = 0.0084
Two factors interaction significant at P = 0.001

Table 8.23 Mean effect on number of ears per square metre of different tillage systems.

Tillage System		
DD	CT	RT
499.0	494.3	563.0

S.e.d. = 22.24
Significant at P = 0.05

Table 8.24 Effect on grain yield (kg/ha) of different sowing methods and seed rates (kg/ha).

Sowing Method	Seed rate (kg/ha)	
	160	140
Broadcasting	1121	1041
Drilling	989	1180

S.e.d. = 49.7
Two factors interaction significant at P = 0.001

Table 8.25 Effect on grain yield (kg/ha) of different tillage systems and seed rates (kg/ha).

Tillage system	Seed rate (kg/ha)	
	160	140
DD	1120	1312
CT	1462	1201
RT	1321	1676

S.e.d. = 122.1
Two factors interaction significant at P = 0.05

8.3 Machine Parameters

8.3.1 Machine Performance

Figure 8.29 shows draught force and actual speed for different implements. The disc plough required a higher draught force and a lower forward speed; the seed drill required a lower draught force and could work at a higher speed.

Ridging and ridge splitting required a low draught force. The direct drill was slightly higher in work rate, but required a much higher draught force. The disc harrow had about half the draught force of the disc plough and was slightly higher in operation speed than the disc plough.

Results of power requirements for different implements (**Figure 8.30**) indicated that the disc plough, the direct drill and the disc harrow required high amounts of power to be operated. The ridger required much less power.

Figure 8.31 shows that there was slight variation in revolutions per minute of the tractor engine with different implements, but the higher values were observed with the disc plough and the direct drill. The actual speed results obtained indicated that there were differences in operational speeds with the direct drill and the conventional seed drill.

Results also showed that fuel consumption was higher with the disc plough, followed by the disc harrow and direct drill, while lower values were observed with the ridging/ridge splitting process, followed by the seed drill.

8.3.2 Field Operation Costs

The conventional tillage system showed the highest power requirements and overall, the highest operating cost. The reduced tillage system employing the ridger clearly shows the lowest cost. Even when ridging is followed by ridge splitting, the cost is still considerably lower (**Table 8.26**).

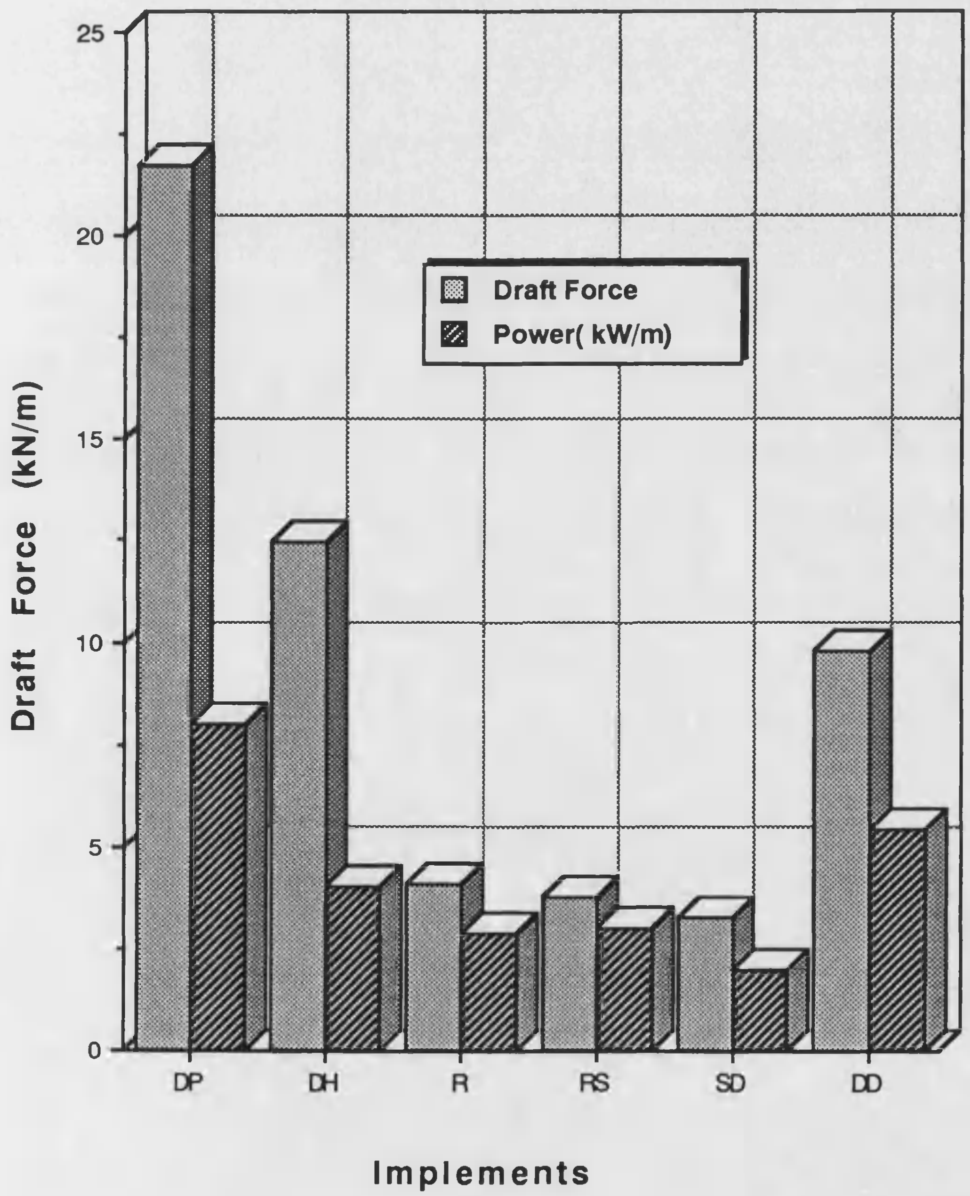


Figure 8.29 Draught force requirements of different equipment.

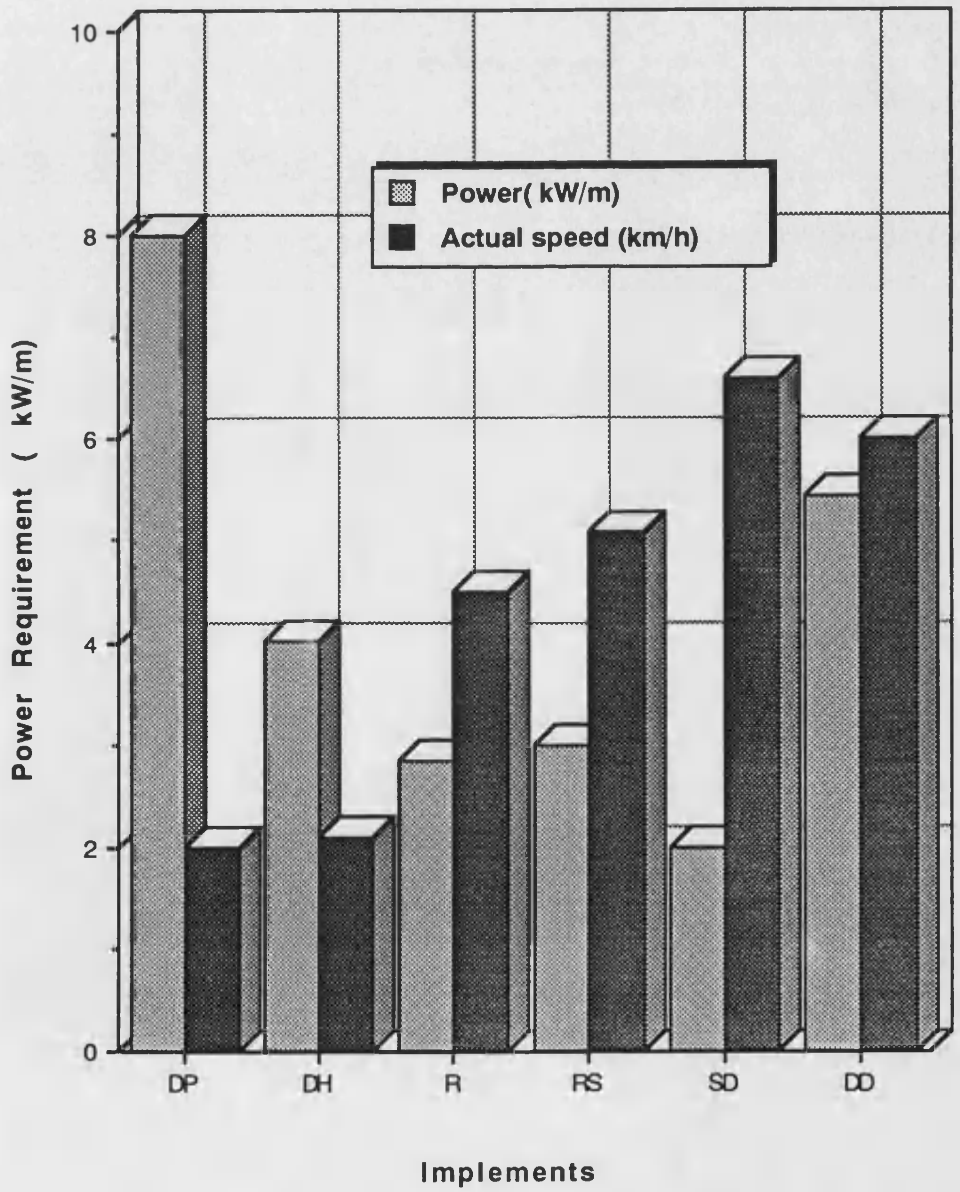


Figure 8.30 Power requirements of different equipment.

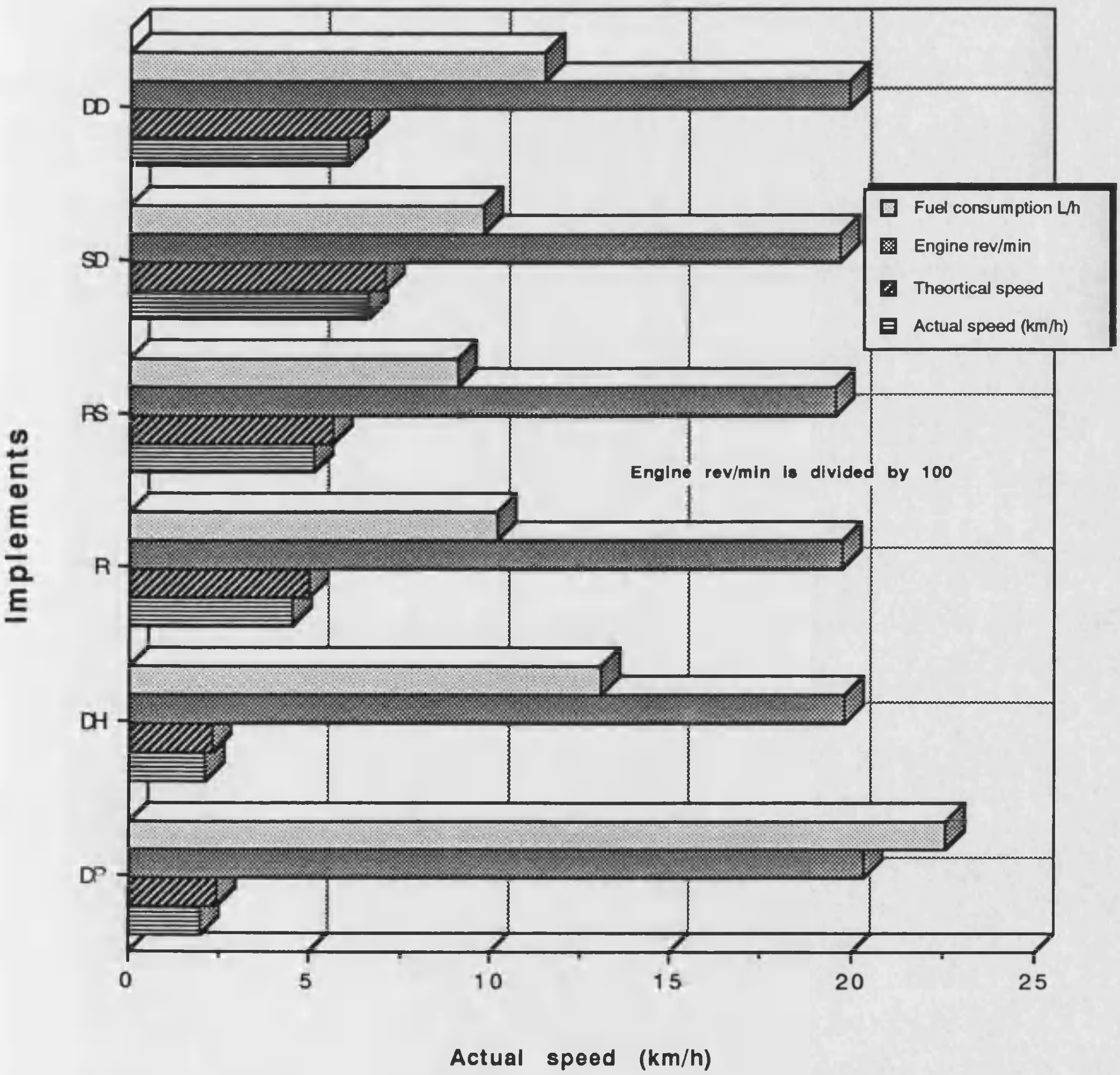


Figure 8.31 Fuel consumption and speeds of different equipment.

Table 8.26 Machine performance and field operation costs of different implements (Season 1994/95).

Equipment and Operation	Forward Speed (km/h)	Draught force (kN/m)	Power requirement (kW/m)	Fuel Consumption (l/ha)	Field Capacity (ha/h)	Operation Cost (Dh/ha)
Disc plough (DH) (25-30cm depth) (1.5m wide)	1.99	21.75	8.01	22.6	0.89	789
Disc Harrow (DH) (Twice disc harrowing at 10cm depth) (1.8m wide)	2.10	12.44	4.02	13.10	1.13	640
Ridging (R) (5-7.5cm depth) (1.8m wide)	4.5	4.11	2.85	10.20	1.68	266
Ridge Splitting (RS) (5-7.5cm depth) (1.8m wide)	5.1	3.80	2.98	9.10	2.25	204
Conventional Seed drill (SD) (5cm depth) (3.0m wide)	6.6	3.27	1.99	9.80	1.96	217
Direct Drilling (DD) (5cm depth) (3.0m wide)	6.0	9.80	5.44	11.50	1.51	893

£1 = Dh12.9 (1995)

9.0 DISCUSSION AND CONCLUSIONS

9.1 Effects on Soil Aggregate Distribution

The randomized photographs (previous section) showed the effect of contrasting tillage treatments on aggregate size distribution on the surface with different implements and the resultant soil surfaces produced. In general, aggregate size distribution was measured as the mean weight-diameter of soil aggregates (Van Bavel, 1949). However, under semi-arid Moroccan conditions, Kacemi *et al* (1992) emphasized that dry mean weight-diameter of aggregate was not significant among tested tillage systems.

Braunack and Dexter (1988) found that an intermediate size of aggregate (2-3mm) resulted in earlier emergence and higher wheat yields on clay soil than with larger aggregates (>4mm) on a loam soil. This is in agreement with Dorenko (1924) and Kvasnikov (1928), cited by Braunack and Dexter (1990) who reported maximum wheat yields with seed-beds of 2-3mm aggregates. This is in contrast with Jaggi *et al* (1972) who concluded that a seed-bed of 1-2mm aggregates with a dry bulk density of 1.2-1.3g/cm^3 would give the best wheat grain yield on a clay soil. Also, Braunack and Dexter (1988) found that finer aggregates (<1mm) tended to restrict aeration and reduced emergence under wetter soil conditions. It seems that soil structural adjustment (i.e. aggregate size control) is required in order to achieve this soil air/water/space balance and also to optimize the prevention of crusts. However, generally increasing soil permeability, decreasing bulk density is obtained by aerating. Also, maximum contact between seed and soil for moisture imbibition and rootlet development are required together with ample consolidation to ensure good control over drilling depth. Weather variations affect cultivation by helping the natural drying/wetting cycles in aggregate size reduction. The first flooding irrigation applied on heavy soils in a hot environment aids soil breakdown; frequent flooding irrigation tends to restrict aeration and earlier emergence could be the result.

9.2 Effects on Bulk Density and Soil Porosity

(a) EXPERIMENT 1 (FIELD 2A)

At the beginning of the growing season, ridging and ridge splitting treatments at different depths showed no variation in bulk density and porosity. Over the duration of the experiment, ridging/ridge splitting with broadcast seed treatment resulted in a lower bulk density. This was probably due to the greater soil disturbance and less soil compaction when manual broadcasting was applied. However, increasing bulk density influenced pore space by decreasing the average of soil porosity at depths of 12-18 cm and 18-24 cm, which was likely to be due to compaction.

The soil porosity was always greater at the soil surface and that agrees with the fact that changes in bulk density and porosity depend on the amount of soil loosening done and soil moisture content. Also, this may be attributed to the influence of reduced tillage depth on soil moisture storage. Culley and Larson (1987) and Nesmith *et al* (1987) found different results, in that light, and no-till treatments resulted in higher bulk density values, after harvest, than that of conventional tillage practices in the 0-10cm layer. These contrasting results might be attributed to the effect of the soil type, intensity of the cultural practices and duration of the growing season.

(b) EXPERIMENT 2 (FIELD 2B)

Different tillage systems showed significant variation within different depths on bulk density and porosity. After sowing, the direct drilled plots had variable bulk density within different depths. This is probably due to the presence of trash and deep cracks in the undisturbed treatment plots. Over the duration of the experiment, direct drilling treatment stayed variable on bulk density and porosity within different depths. However, by the end of the growing season, all tillage systems generally showed increased bulk densities at different depths.

There were significant variations in bulk densities and soil porosity values below the depth of 18-24cm. This was mainly attributed to the breakdown of soil aggregates on the surface during subsequent flooding irrigation and cumulative settling and packing of soil particles.

It seems that surface disturbance with reduced tillage (5-7.5cm deep) may cause the filling of soil cracks to some extent by pulverized soil from the ploughed layers above; this may also have contributed to higher bulk density values during the growing season, together with the settling of soil particles over the duration of the experiment due to the effect of flooding irrigation.

The warm, relatively humid climate of Morocco and the semi-arid vertisol soils may also influence the values of bulk density and soil porosity of the undisturbed surface of direct drilling treatment plots compared with the other tillage treatments. The presence of deep cracks in the direct drilling treatment plots which closed after wetting and swelling, so reducing the pore space in the soil, could also influence these values. Similar results have been reported by many researchers (see, for example, Duley, 1939; Parker and Jenny, 1945; Russell, 1950; Adams and Hanks, 1964; Godatt, 1980; Vander Tak and Grismer, 1987; Cabidoche and Ney, 1987).

In Pakistan, Mughal (1973), working on black cotton soils, found no significant differences in the average bulk densities between different tillage practices. However, the greatest bulk density was observed at 0-30cm depth in tractor drawn tined cultivator plots.

In general, at all depths, conventional tillage resulted in the lowest bulk density, followed by reduced tillage (ridging at 5-7.5cm). This may have been due to the soil loosening at the depths. This agrees with the results found by Soane (1975) and are further supported by Burnett and Tackett (1968), who found that four years after roto-tilling and three years after mixing with a ditching machine, the bulk density of loosened soil was still lower than that at similar depths in conventionally tilled plots.

Several reports have indicated contrasting results from the effect of tillage on bulk density and soil porosity. Blevins *et al* (1983a) reported that tillage had no effect on bulk density after a ten-year period of tillage treatments on a medium textured soil. However, other researchers have reported a drastic increase in bulk density with no-till compared to mouldboard ploughing of a clay loam soil (Griffith *et al*, 1977; Gantzer and Black, 1978). Blevins *et al* (1983b) found similar bulk density values with conventional and no-till systems and lower bulk density with chisel tillage on poorly drained soil. Pelgrin *et al* (1990) reported that bulk densities, measured three weeks after tillage operations, were similar in the upper 20cm of a sandy loam soil where tillage was done with a disc plough, mouldboard plough, cultivator, disc harrow and no-till. They indicated that the bulk density values increased with time and were significantly higher in no-till, disc plough and cultivator than mouldboard plough and disc harrow.

Bulk density, soil porosity and penetration resistance are physical properties widely used to assess soil loosening or compaction in tillage studies. However, the difficulty in using bulk density to investigate soil strength or to detect tillage depths is related to the fact that it is tedious and time consuming. Carter (1988) found that resistance to penetration was much more effective in detecting zones of soil strength, depth of tillage and the extent of tillage induced soil loosening or compaction and the degree of their persistence over time than other methods.

9.3 Effects on Soil Penetration Resistance

(a) EXPERIMENT 1

At the beginning of the growing season, there were significant variations in penetration resistance at different depths on all plots associated with sowing methods. This may be attributed to the presence of deep cracks in the shallow disturbed surface produced by the ridger (5-7.5cm depth) and associated with the first application of excessive flooding irrigation after sowing, because much water was required to fill the soil cracks.

Over the duration of the experiment, there was a significant increase in variation between treatments at different depths, especially in the upper layer of 20-30cm with different sowing methods. This may be mainly attributed to the resettling of clay soil particles during subsequent irrigations. Also, the uneven accumulation of crop roots at 20-30cm deep after two months.

By the end of the growing season, all tillage treatments showed some differences in soil strength values, mainly at depths of 5-25cm. This was probably due to the presence of crop, rainfall and irrigation water which recompacted the soil. However, the least resistance to penetration recorded was the treatment of ridging only, with seed drilled at the lower seed rate. This was probably due to the more even distribution of plants on the surface following the use of the seed drill.

(b) EXPERIMENT 2

After the first irrigation, direct drilling showed a greater resistance to penetration at all depths, while conventional tillage at all depths resulted in the lowest values. This may be due to the soil loosening at these depths and agrees with the findings of Soane (1975). However, reduced tillage at 25-40cm depth showed differences in penetration resistance values, probably due to the deep cracks and the shallow work of the ridging operation on the soil surface.

Over the duration of the experiment, at the layer of 20-30cm deep, reduced and conventional systems had differences in penetration resistance values. This may have been due to the effect of deep cracks on the reduced tillage plots as mentioned earlier and to the resettling of soil particles after subsequent irrigation for conventional tillage.

By the end of the growing season, direct drilling stayed with higher values in resistance to penetration at all depths with both seed rates. However, conventional tillage came closer to the reduced tillage treatment in the values of penetration resistance (irrigation water recompacting the soil). Sowing at 160kg/ha always had greater soil strength; most probably due to the greater amount of seed sown, resulting in a greater amount of crop roots which reduce penetration resistance. Conventional and reduced tillage systems at depths of 5-20cm resulted in similar soil strengths. This was probably due to the soil moisture content at the surface, attributed to the resettling of clay soil particles during subsequent flooding irrigations with the influence of tillage on soil moisture storage. The experimental site was fallow for the three previous years; however, different experimental plots may have received different amounts of water due to the undulation of the soil surface and different width of cracks. This variation in amounts of water on different parts of the plots caused by the undulation of the land and flooding irrigation had significant effects in all factors involved in the experiments.

Tom (1972) reported that Zeinelabedin and Robinson (1971), in a study of some Gezira soils in the Sudan, found that the width of cracks was affected by the length of the drying period, and by the type and clay content of the soil. They also found that the total volume of cracks in the upper layers of the Gezira vertisols they studied were much affected by their recent soil cultivation history and vegetation present, such as grass and trees. The amount and frequency of rainfall also affects the amount of cracking which takes place.

The effect of soil compaction is not always consistent. For example, a positive and a negative effect on wheat growth was observed by Feldman and Domier (1970), depending on when the compacting forces were applied relative to planting time. Such a range of effects was also noted depending on the depth of the compacted soil layer (Agrawal *et al*, 1975). Indeed, compaction characteristics of soils are modified by the previous cropping history of a particular soil (Voorhees *et al*, 1985). These authors found that while the cropping history did not affect bulk density of compacted soil, inter-aggregate porosity was affected; the penetration resistance index was directly related to this parameter. Also, the type of tillage system is another factor involved with soil compaction.

Asoegwu (1987) reported somewhat different results: at harvest time, about 70% of the plant roots were found at 10-15cm depth, with soil strength reduced and more variable than at planting time. Tillage was found by Sharma *et al* (1988) to decrease soil penetration resistance significantly.

Pelgrin *et al* (1990) reported that soil penetration resistance, measured immediately after tillage application, was identical among tillage treatments in the upper 15cm, and significantly different between 15 and 40cm depth. They found that soil moisture content caused by flooding irrigation water affected the upper layer of the soil surface. Tom (1972), in his study of the moisture content of vertisols in the Gezira (Sudan), found that the maximum water holding capacity for the soil is over 60% and the optimum moisture range for plant growth is 36 to 40%; the lower limit of readily available water is 28% and at 23-24%, the crop is 'ruined' under semi-arid conditions.

9.4 Plant Parameters

9.4.1 Effects on Plant Population (Plants/m^2)

(a) EXPERIMENT 1

Different practices of reduced tillage system and sowing methods showed significant differences within different weeks after sowing on plants/m^2 which was possibly due to the different sowing methods and amount of surface disturbance.

The ridging treatment with broadcast seed always resulted in the highest value of plants/m^2. However, eight weeks after sowing, the plant population became reduced by about 10 plants/m^2, probably due to the lack of land levelling which caused patches of waterlogging over the plots.

In the second week after sowing, the broadcast treatment had a higher number of plants/m^2. It seems likely that this was due to the presence of seeds at shallow depths compared to the seed drilled at a depth of 5cm which needed more time to emerge.

In the third week after sowing, the ridging treatment with lower seed rate had a higher number of plants/m^2 with both sowing methods. This indicates that the ridging alone (5-7.5cm depth) may have achieved a suitable condition for emergence.

(b) EXPERIMENT 2

The reduced tillage system always resulted in more plants/m^2 during the period of experimentation, compared with conventional tillage and direct drilling which were always less than 300 plants/m^2. The maximum population, with reduced tillage was 349 plants/m^2. However, after the fifth week of sowing, there was a reduction of about 15 plants/m^2, probably due to the uneven distribution of irrigation water.

Benaouda and Bouaziz (1992) surveyed fields in the Chauoia region of Morocco and reported that the grain yield was very much dependent on the emergence rate, which determines the initial stand and the best yield was obtained by an initial stand of 400 plants/m^2. Above or below this limit, the yield decreased. However, the seed losses during crop establishment were mainly due to mechanical obstacles at the soil surface and were the result of seed-bed preparation during inappropriate soil conditions such as when it was too wet. The farmers, well aware of these losses, compensate by using higher seeding rates to obtain adequate stands.

Results showed that a lower seed rate produced a greater number of plants/m^2 (approximately 300 plants/m^2). The reason for this is not clear, but it may be attributed to the fact that a reasonable number of seeds at the lower seed rate found favourable environmental conditions. The pronounced effects of the ridging operation as a reasonable surface disturbance may have an influence on wheat growth during the first part of the growing season. Mahmoud (1985) and Meek *et al* (1988) found that different soil disturbance had an influential effect on crop growth due to its effect on soil structure.

9.4.2 Effects on Leaf and Tiller Development

(a) EXPERIMENT 1

At the ninth week after sowing, seed drilled at the lower seed rate resulted in more leaves per main stem of plant. This may have been due to the even distribution of sowing, with the seed drill and may also be dependent on the variety of wheat (Achtar G2). However, employing a ridging treatment with seed drilled at a lower seed rate always resulted in more stems per plant. This was possibly due to a more even distribution of seeds under the surface.

(b) EXPERIMENT 2

Different tillage systems at different seed rates showed significant differences in total number of leaves per main stem of plant during the twelve weeks after sowing. This may be due to the amount of soil loosening and the beginning of the tillering stage of the wheat which usually starts after the fifth week following sowing.

Reduced tillage always resulted in more stems per plant between seven and twelve weeks after sowing, while the other tillage systems showed significantly lower numbers.

Reduced tillage plots developed an average of 27 leaves per plant; however, plants grown from conventional tillage produced 20 leaves per plant and 17 leaves per plant with direct drilling treatments.

Results showed that reduced tillage also resulted in a higher number of leaves per stem and each stem attained 7.0 leaves, compared with conventional tillage, 5.6 and direct drilling, 5.0. This may be due to the favourable soil surface disturbance caused by the ridging operation, compared with the deep cultivation and no-till treatments.

These results are in agreement with the results of Yousif (1987) obtained on the irrigated clay soils of the Gezira (Sudan).

9.4.3 Effect on Yield and Components

(a) EXPERIMENT 1

The largest grain yields were obtained by drilling at 140kg/ha or broadcasting at 160kg/ha.

(b) EXPERIMENT 2

Reduced tillage showed the greatest number of ears/m^2 followed by direct drilling. The conventional system showed lower ears/m^2, which may be due to the vertisol's compaction following continuous use of conventional tillage implements.

Reduced tillage at a lower seed rate resulted in a considerably better grain yield compared with the other tillage systems. Furthermore, ridging only, with seed drilled at a lower seed rate, resulted in a higher grain yield.

It seems that the ridging operation at shallow depth could have contributed to the well-developed root systems. Generally, most roots of the wheat crop are at the shallow depth; it may be that the enhanced nutrient and water uptake resulted in increasing ears/m^2 which, in turn, was reflected as a higher yield.

9.5 Machine Performance and Operation Costs

The lowest draught forces were associated with the ridging and ridge splitting operations. The direct drill required a much higher draught force, this mainly being due to the weight of the drill and the penetration operation of the disc coulters on the untilled soil surface for the sowing process. The direct drill was higher in work rate, this being due to the operating width of 3.0m. The disc plough required a higher draught force, the disc harrow required about half the draught force of the disc plough and was higher in operation speed, this being mainly due to the difference in working depths. The disc plough and disc harrow are traditional Moroccan tillage implements and require a high power input to operate. The direct drill also has a high power requirement. The actual power required is dependent on the equipment width, working depth and field conditions.

Other field operations showed that ridging followed by ridge splitting and drilling with the conventional seed drill required much less power at the same constant operational speeds.

The difference between forward speeds of the semi-mounted direct drill and the conventional seed drill was less than 1.0km/h and generally, the trailed seed drill was slower in turning, which directly reduced the work rate. This is an important factor during the agricultural season in semi-arid regions due to the short sowing period, rainfall and limited availability of machines between farmers.

Fuel consumption was higher with the disc plough, mainly due to the high amount of soil lifting. However, lower fuel consumption was observed with the ridging/ridge splitting process and the conventional seed drill. However, the Autotronic tractor used for the test in the field has an engine of 92hp, which requires more diesel for running; in practice, it would be possible to use a lower powered and therefore more economical tractor.

Field operations confirmed that increasing the depth of cultivation with conventional tillage (disc plough and twice disc harrow) mainly caused increased power requirements and cost. A skilled operator is required to achieve a good standard of ploughing and harrowing and this also increased the cost.

The costs of operating the different equipment were considerable, being caused by the high cost of diesel fuel and the running cost of the tractor. The direct drilling had a work rate of 1.51ha/h with an operation cost of 893Dh/ha. Much of the cost is due to the basic cost of the machine. However, the conventional tillage system had a higher cost of 1429Dh/ha and a lower work rate.

Reduced tillage consistently resulted in a lower cost of operation; ridging only cost 266Dh/ha, while ridging followed by ridge splitting cost 470Dh/ha and had a higher work rate. Reduced tillage combined with the drilling operation could reduce the cost by a half compared with direct drilling. The cost of the reduced tillage system was also approximately a third of the cost of the conventional system.

Other considerations with the conventional system are the availability of tractors and implements. This is due to a shortage of machinery available to farmers. The conventional practice also has a lower rate of work and requires more skill from the operator.

Dycder and Bourarach (1992) also found significant variations in their results obtained when assessing machine measurements for different implements among different treatments under Moroccan conditions. Bourarach (Pers. Comm.) emphasized that there are also significant differences in field operation costs, depending mainly on the type of equipment and its availability during the growing seasons.

The results obtained here are also in accordance with the findings of Cary and Rasmussen (1979) and Ahmed and Haffar (1993), who found considerable variations in the machine performance for a comparison between different tillage practices.

9.6 Conclusions

The results obtained in this study showed that the physical properties of the soil such as aggregate sizes, penetration resistance, bulk density and soil porosity on different test occasions were directly affected by the tillage systems used.

These effects were reflected in crop performance measurements of plant count at establishment stage (plants/m^2), leaf and tiller development, and yield and components.

The results indicate that the shallow ridging operation only, as a practice of reduced tillage can improve wheat yield and may be used successfully with a conventional seed drill at a lower seed rate to increase grain yield, especially in vertisols affected by compaction caused by the continuous use of conventional tillage implements in hot irrigated environments. The system also had a lower operating cost and a higher work rate.

It was observed that the first excessive water application after sowing helped to some extent, by breaking down some clods on the soil surface. Also, it was observed that lack of levelling and uneven distribution of the flooding water which then fills soil cracks is likely to cause waterlogging and the washing out of seeds from the surface, leading to failure to germinate, mainly affecting plants/m^2.

There are many problems associated with the measurement of soil water content from different tillage treatments and at different depths. These problems are generally expected to give misleading information and are summarized in the following points:

a) Different experimental plots may receive different amounts of water at each irrigation, due to the absence of measuring devices at the experimental site.

b) The presence of deep cracks in the untilled and shallow-disturbed plots, and the absence of even levelling in ploughed plots may lead to uneven distribution of water inside the plots.

c) The water conserved in the soil profile may be lost through drainage to deeper layers beyond the reach of the plant roots.

d) Flooding water comes from the river resource through main channels and sub-main channels. This water may carry salinity and water-borne diseases and may contaminate the soil and plants causing poor establishment.

A comparison of the conventional tillage system used in Morocco and the proposed Reduced Tillage System is shown in **Figure 9.1.**

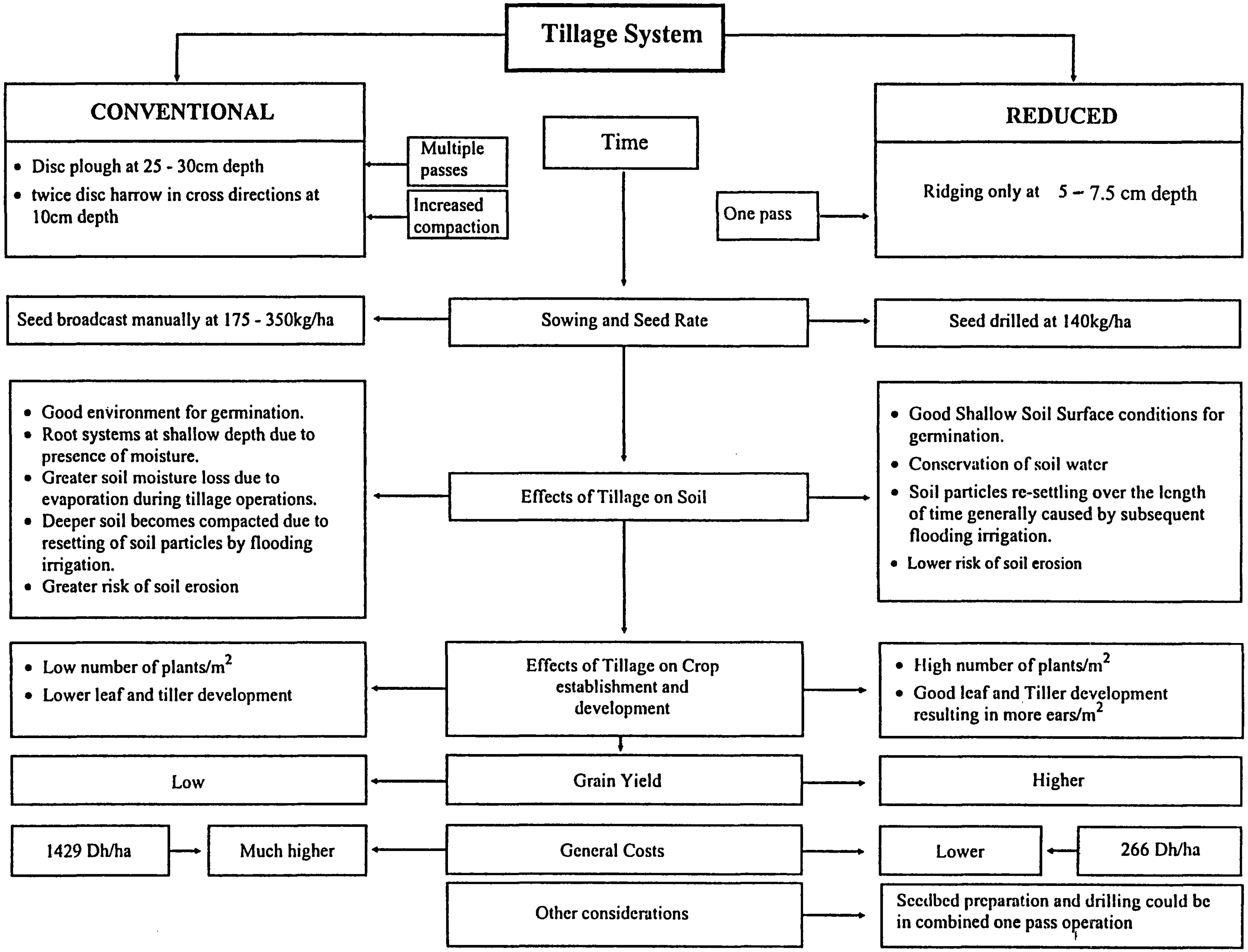


Figure 9.1 Comparison diagram of tillage systems used in semi-arid conditions with flooding irrigation

PART THREE - GENERAL DISCUSSION AND CONCLUSIONS

10.0 GENERAL DISCUSSION

10.1 Improving Wheat Production in the Sudan and Morocco

The desire to grow wheat on an increased scale in Sudan and other countries in North Africa has meant that attempts are being made to cultivate it in areas such as the Gezira, where it is not a 'traditional' crop. Wheat is being grown on soils which are not ideal for it, in climates for which it is not well suited and by farmers who lack experience of the cultivation and irrigation techniques required. Also in these countries, lack of materials, equipment and knowledge based on scientific investigation is common, so it is inevitable that problems arise.

Some work is in progress (Elahmadi *et al,* 1993) towards the provision of varieties more tolerant to high temperatures; there is a gradual improvement taking place in the provision of the means to control pests and diseases and there is now investigation in progress designed to improve crop establishment techniques.

In the latter context it is interesting to note that Mohamed (1992) found that many farmers growing irrigated wheat were keen to try different seed-bed preparation methods in the belief that they might get better yields - implying that they realized the guidelines they had been following were less than ideal.

Elhag (1992) found that there was an interest amongst Gezira farmers in the concept of minimum tillage for wheat. This interest has developed from the fact that the technique has been widely adopted by growers of rain-fed crops of sorghum and sesame elsewhere in the Sudan, the basis of their interest being the reduced cost of cultivation and the availability of suitable implements.

The problem with a short-term crop such as wheat is that if the establishment phase of the crop cycle is not successful, the low initial plant population is unable to tiller and spread sufficiently to yield satisfactorily. It follows, therefore, that the early stages of establishment of the crop are critical. The supply of water is also critical throughout the life of the crop, although there is probably more latitude for uneven distribution later in the growing season, when the root system has developed, than during the seed/seedling phase.

The writer undertook research into seed-bed production in the Sudan. The machinery options available for this investigation were limited, for example, it was not possible to study the performance of a direct drill and the range of other cultivation and drilling equipment available was small. The cultivation implements available were chisel ploughs, disc ploughs, disc harrows and ridgers.

Of the choice of implements, the conventional ridger showed some potential as the basis of a new reduced tillage technique. Used in the way described earlier, it performed creditably when compared with the standard method of seed-bed preparation based on disc harrows. Why this happened cannot be identified with any confidence; the measurements taken during the experiment did not produce conclusive evidence, so this must be an area for further investigation. However, it was observed that the disc harrowed plots in the experiments in both Sudan and Morocco slumped during the first irrigation after sowing: the soil became 'sad' and as it dried out, became hard and dense. The suggestion is that the germinating seeds suffered some degree of oxygen starvation. This view is supported by Braunack and Dexter (1988), who found that finer aggregates (<1mm) tended to restrict aeration and reduced emergence under wetter soil conditions.

Another possible reason for the encouraging performance of the ridger is that it may have promoted more even distribution of water than disc harrows. It is suspected, but again cannot be proved, that water tended to follow the 'residual' furrows, left after the furrow/furrow splitting/Camara operation, leading to a more rapid initial irrigation (using less water) than was the case on the disced plots in the experiment.

As far as is known, ridgers have not been used for small-seeded cereal seed-bed production before. The technique used in the Sudan was ridging and ridge splitting at 10-15cm depth on flat land with three sizes of ridge. This was repeated with modification by ridging alone and ridging/ridge splitting with a shallow depth of 5-7.5cm. The results suggest that further investigation would be required before a recommendation could be made. Although there seems to be some potential in ridging alone with drilling at a lower seed rate, there are limitations to the range of ways such a simple tool can be used: the time in which it can be used is limited, and although it can be set at different depths, at different spacings and can be equipped with different shapes of wing, the range of options is clearly limited.

Points in favour of the ridger are low initial cost, low cost of operation, ready availability, low level of skill required for maintenance and operation and the ability to work in a wide range of soils and soil moisture contents. Similar points apply to the Camara, so if there are no unforeseen drawbacks, there seems to be no reason why the combination should not be taken up by those farmers with access to a modest tractor.

Babiker *et al* (1991) and others, have stressed the advantages of drilling over broadcasting; unfortunately, conventional drills tend to be relatively expensive items, and one approach that might offer a cheaper way round this problem could be develop a seed metering device which delivers seeds to coulters mounted at the front of (or within) a Camara. This approach is similar to that used to sow field beans in conjunction with a mouldboard plough, and by the writer to sow barley whilst using a plough/furrow-breaking rotor combination.

Weed control is one area in which use of the disc harrow may be better than the ridger, although if the ridger is used twice and at a greater depth than is probably necessary for the production of a seed-bed, this may not be so. An alternative approach might be to use a shallow pass with a cultivator fitted with 'A' blades first, the aim being to move the soil to a depth of some 5cm before the first pass of the ridger.

A problem that may have been associated with the use of a ridger at a shallow depth was that the soil between the furrows could have been too hard for coulter penetration. This fear was unfounded, even on the heavy clay soils in the Gezira, because the ridger tended to create fissures in the soil between adjacent bodies, and these weakened the mass of soil sufficiently for drilling to proceed without difficulty.

A further aim of the research, supported by experiments in Morocco, was to see how far apart the ridging bodies could be set before establishment and yield started to suffer. The depth of working will obviously have a bearing on this, but due to the limited availability of technical assistance, little could be done to study this relationship. It was thought it would be a better use of resources to have a comparison between the ridging treatments studied in the Sudan and direct drilling.

The opportunity to use equipment to measure the power requirement and fuel consumption of the tractors and implements also had the effect of limiting the number of cultivation treatments used, even though it was realized that these aspects are of secondary importance compared to crop yields.

At the present time, direct drilling is not an option in the region concerned, as the equipment is not being imported.

Even in Western Europe, it has had only a limited uptake, virtually always in association with the use of herbicides or straw burning, and seldom without the occasional use of mouldboard ploughing. Eventually, direct drilling may have a place in Africa and it is essential that trials with this and other approaches used in the more developed world continue, so that at the appropriate time, decisions can be taken about the direction in which to encourage farmers to proceed. The benefits of the direct drilling technique are conservation of soil moisture, together with a saving in time and cost. It is attractive as a one pass operation which could be of particular benefit in the non-traditional wheat growing areas due to the limited sowing time available.

10.2 The Effects of Technology Transfer

Appropriate technology for agriculture in less developed countries has been a subject of considerable discussion at international meetings of agricultural scientists and social scientists.

In particular, attention has been focused on agricultural mechanization, especially since the traditional technologies of hand and oxen power limit the enlargement of farms (Crossley and Kilgour, 1983).

Many African countries have economies based on agriculture. Sudan, Ethiopia, Kenya, Malawi and Tanzania, for instance, all have eighty per cent or more of the population classed as agricultural. In these countries, the relationship between agricultural employment and appropriate technology for mechanization policies is important and directly related to structural change in agriculture (Simpson, 1974). However, this effect has been obvious since tractors were first introduced into the Gezira Scheme for cotton production.

Clayton (1983) states that in the long term, the process of development should involve the substitution of mechanical power for human and animal effort and that this would appear to be essential to the achievement of a sustained increase in real incomes per head. He further states that the immediate and short-term consequences of mechanization are of predominant importance to the welfare of the developing countries. His conclusion was that it is not only the economics of mechanization at the farm level that have to be considered, but also the impact of mechanization on the social and political framework.

A key issue for consideration is the effects of mechanization which have increased income inequality, rural unemployment and landlessness.

At farm level, a tractor represents a large investment and a loan to enable its purchase may be beyond the capacity of most small peasant farmers, but in the Sudan, the effective role of the Agricultural Banks and Co-operative Groups is to encourage farmers to have medium size tractors by offering attractive terms and conditions of agreement. Within the agricultural community, the scale of economies achieved, in favour of large farmers, means that increased market activity comes principally from these larger farms. Over time, the increased supplies tend to lower market prices with the result that small farmers could be much worse off in income terms as a result of bias in favour of big farmers (Bell, 1971).

In Africa, where communal ownership of land and small owner-occupiers prevail, Clayton (1976) has shown that mechanization has progressed relatively slowly, and has had little effect on income distribution or employment. Although a faster rate of mechanization may give rise to increasing income disparity and labour displacement, the main problem is to identify situations where tractors are economic to the farmer. There are situations where the apparent paradox of the benefits of mechanization do not and need not apply: where mechanization increases both income and employment.

This can happen where mechanization releases labour for profitable employment elsewhere, either outside the agricultural sector or within it, when cultivatable land is available. This gives rise to more labour intensive farm practices and/or farming systems; where it increases cropping intensities; where it is land-releasing (displacing animal draught) and where it is land-augmenting (in combination with the use of high-yielding varieties). Forbes-Watt (1966) observed that mechanized cotton cultivation in Uganda was economical and employment-generating.

Experience showed that by releasing labour normally used for cotton land preparation and by hiring tractors, farmers were able to use this freed labour to cultivate more millet. In turn, this enabled the farmer to hire more labour to intensively cultivate and harvest the larger cotton crop.

However, the continuing high level of population growth in developing countries has increased the 'dilemma' of mechanization, avoiding loss of jobs while reducing the physical toil and drudgery of agricultural work. This is one of the causes of the drift of young people and school leavers from agriculture to towns. Development of a new policy to make agriculture more attractive to youth and reduce rural to urban migration needs to provide more attractive incomes, to lower the physical effort required and to provide the possibility for young people to work with machinery, which would prepare them for the future.

There is a definite requirement to provide them with training in the operation and maintenance of tractors and equipment and in all aspects of safety associated with machinery and workshops.

Situations where improvement in the standard of living of individuals conflicts with social welfare losses (i.e. health, education, electricity, sanitation, communication and other services) are often generally associated with the use of mechanization.

Lost farm jobs could be accepted if mechanization generated other employment opportunities; widening income disparity could be tolerated, providing the incomes of farmers without a tractor continued to increase. Increased landlessness following mechanization need not be a serious problem, providing additional full-time farm jobs match the lost farm income. The provision of an appropriate infrastructure in the rural areas of Sudan, particularly roads, would reduce the cost of transporting and also reduce the fuel cost, particularly during the critical sowing and harvesting seasons.

From the rapid mechanization process in Pakistan, Donaldson and McInerney (1975) have seen the social costs of mechanization, especially those distorting the farm structure against the small holder sector and its associated increased landlessness. This could become problematic even where the private net benefits to larger farmers and an increased surplus for consumers are taken into account. Such a situation may justify the discouragement of mechanization by the government, but this would have to be done with caution. A strategy which gave exaggerated emphasis to employment generation, narrowing income disparities or even preserving the farm structure could induce income and other trade-offs of an unacceptable magnitude to poor countries. This is of particular importance in the Sudan, where land tenure systems are common.

The process of technical transfer as it is now known, is a particularly difficult one in agriculture. Under North African countries, the lead in the process is usually taken by a few large growers working in conjunction with whatever research/extension services exist in a particular country (de Wilde, 1967). **Figure 10.1** shows a simplified picture of the role of agricultural extension in transferring information to farmers.

Further uptake will depend, above all, on economic circumstance, for instance, whether the technology is expensive to install, the benefits produced and how reliable they are, whether the workers in the industry are likely to be able to apply the technology and, if not, the length of the training and its cost.

An example in agriculture of where technology transfer is proving difficult is in the safe and effective application of agrochemicals (Kannan, 1992). Chemicals are expensive, manufacturing is a highly specialized industry, sprayers are not simple pieces of equipment, some of the materials are hazardous to operators and specialized training is not always available, decisions about which substances to use and how and when to use them is a specialist's job and the benefits are often difficult to evaluate. Hence the relatively slow rate of uptake of technology transfer in this field.

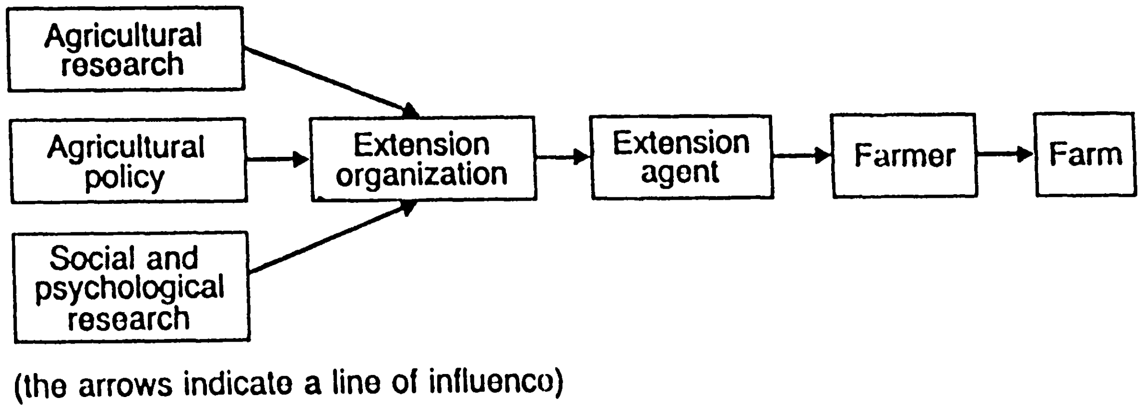


Figure 10.1 Information flow in agricultural extension (Van den Ban and Hawkins, 1988).

The introduction of, say, direct drilling on its own would obviously be less difficult than that of agrochemical application, but if the latter proved to be an indispensable feature of the overall process, then it can be assumed that it will be an extremely slow process.

Stages of Adoption Process

1 - awareness
2 - interest
3 - evaluation
4 - trial
5 - adoption

As well as considering the individual, the process which determines the speed at which various innovations, agricultural or otherwise, are adopted within a group, or become diffused over a country, is partly influenced by national forces, e.g. agricultural policy, fiscal constraints, availability of innovations.

Factors Enhancing Technology Transfer

1 - The characteristics of the technology itself.
  (a) economic characteristics
  (Initial set up cost, operating and maintenance cost, rate of return on investment, net effect on farm income.)

  (b) technical attributes
  (Complexity, compatibility with existing practices, trialability, attractiveness and visibility.)

2 - The media of communication.
  (Mass media: radio, T.V., press; neighbours and farming acquaintances, agricultural advisory services, salesmen.)

3 - The personal and sociological characteristics of adopters.
  (Farm size, income, age, education, land tenure, socio-economic status, social origin.)

Factors Limiting Technology Transfer

1 - Personal and sociological characteristics.
  (Such as low level of income, knowledge, part-time and elderly farmers.)

2 - Socio-economic status.

3 - Area isolated by physical features from other neighbourhoods.

4 - The use of information and advisory services.

5 - The degree of farmers' social participation in activities.

6 - Old customs, traditions and values.

7 - The nature of new technology itself (cost and complexity).

References: Adams (1982); Van den Ban and Hawkins (1988); Roling (1988); Hunter (1969); Jones (1963); Jones (1967); Gasson (1973).

10.3 Some Implications of the New Technology Applied in the Sudan

In this section, the matters outlined in 10.3 are considered in the light of the Sudan specifically.

- New technologies, particularly farm mechanization and irrigation, have contributed to the intensive use of human labour, increased crop intensity and land productivity and created rapid expansion of total farm output. Adequate rainfall is an important factor in the Sudan, particularly in those regions entirely dependent upon it.

- Technology has been found to generate a positive income distribution effect among farm operators, large or small, and also among landless labourers. Therefore, this would directly encourage the land tenure system to develop attractive agreement terms and conditions between the landlords/government and the tenant farmers. Long term leasing has advantages as it is more secure. This land tenure system is now being applied widely in the Sudan.

- The social impacts of new technology are positive in relation to the distribution of economic bases and sources of wealth of farm families in general and of technology adopters in particular. In addition, the effect of technology is also distributed to related sectors such as tractor providers and repair and maintenance services.

- Associated with technological change in rural areas, the socio-economic environment of the community is improved and the family lifestyle and consumption behaviour is changed to that of a modern society.

10.3.1 Implications for the Family

- The literacy rate of the younger generation has improved considerably in rural areas of Sudan. This is evident from the insistence of parents in mechanized households that their children must attend school. The future generation will be more literate and skilled in specific areas, enabling them to handle and seek independent occupations even outside agriculture. This also has encouraged girls to undertake education to at least primary level, thus postponing marriage.

- Living standards have improved in the rural areas, due to an increase in family income.

- The use of mechanical devices such as tractors and water pumps has created a market for after-sales service, maintenance and training facilities. Investment in machinery has meant that households in the Sudan have become very conscious of optimizing its use either in assisting the family with its land cultivation or renting machinery out to others. Successful maintenance of the investment is therefore of primary importance.

- As women develop an enhanced economic position and educational status in the family, they become less dependent upon agricultural activity.

- Diversification of the sources of income in the mechanized family has also encouraged women to take a more active role in family economics, such as the development of new craft skills and the management of a small business.

- The improvement in economic conditions has led to a higher demand for social services, particularly those concerned with education and health. Creation of new relationships has encouraged greater mobility, which has encouraged the use of leisure pursuits and in the case of women, the development of women's societies and associations, both at village and regional level.

- The effect upon the family as a unit has encouraged new forms of co-operation. The male head of the family no longer makes all the decisions alone, but in most cases, shares the responsibility with other family members.

- As education of the younger generation becomes more widespread and the general level improves amongst the mechanized farm families, the young people may leave the village and settle in the urban areas, though the extended family relations are likely to continue for some time. The mechanized farm household may ultimately become too old to manage the farm. This has two potential implications: the first is that during the transition period, the elderly people of the mechanized household might have to depend increasingly upon the skilled agricultural labourers to operate their machines and manage the farm activities, which is a positive implication. In the next stage of change, the ageing parents of the educated younger people might decide to sell their farm to others in the village to spend their old age in the urban areas.

- It is the general impression of the writer that government extension services in the rural areas are still inadequate and more resources should be directed to providing and encouraging extension agents, particularly those concerned with agriculture and infrastructure services, in rural centres. The role of the extension organization in the Sudan requires much more financial support for success, particularly in the provision of transportation and demonstration equipment.

10.3.2 Implications for the Community

- The process of land preparation has been speeded up by the introduction of mechanized tillers and tractors. Multicropping has been encouraged by irrigation, fertilizers and agrochemicals. This has also resulted in agricultural labour being used throughout the whole year.

- Farm mechanization has led to increased non-agricultural activities, particularly service activities, such as provision stores, repairers of tractors and machinery and small hotels. There is scope for developing such services in and around mechanized villages for the benefit of a cluster of villages.

- There has been increased importance attributed to rural marketing activities, particularly those concerned with the sale and transportation of agricultural produce. At the same time there has been increased development of community organizations. Some of these have arisen among farming groups, others have been encouraged by government agencies.

- Farm mechanization and the resultant growth in farm income has increased the savings of people. These savings are partly going into consumption and partly into land and other asset acquisition. In the Sudan, the larger scale farmers are still seeking more land and are purchasing the lands of small and marginal farmers on favourable terms. This may be useful from the point of view of those households, but it is not desirable from the point of view of the community and the country. This has increased the gap between the landless peasants and the big farmers.

- However, parents insist that their children must attend school and they encourage them to do so by making a dowry available from their savings after the children have completed their schooling.

10.3.3 Implications for Government

- The role of the government of Sudan as provider of distress relief will be reduced as the income of the rural families increases. The government, however, will need to improve infrastructural development and services to satisfy the demand for higher living standards.

- The important advantage of mechanization has been recognized as the relaxing of time constraints in the cultivation cycle. This has allowed time for the introduction and development of other forms of agriculture such as new crops.

- Mechanization together with multicropping has had the advantage of making some countries self-sufficient in their staple grain products. This is particularly relevant to the Sudan, as the importation of wheat into the country was banned in 1990.

- The introduction of mechanization has also had an effect upon the livestock population in rural areas when tractors have replaced draught animals. An additional effect of this is that grazing land no longer required can be brought into the cropping programme.

- The improvement in family economic circumstances has led to a demand for credit facilities with low interest rates for the rural poor. However, the inability to obtain credit is still a major consideration in restricting further mechanization. Aligned to this need for credit is the need for greater research into appropriate technology and the development of machinery which is cheap, strong, simple to use and socially acceptable. (Hunter, 1969; Campbell, 1990; Clayton, 1983; Van den Ban and Hawkins, 1988.)

10.4 The Hypothesis

The hypothesis stated earlier in this thesis (1.5) is that there is potential for improving the yield of wheat in North Africa through a modification of the cultivation systems used. To test the hypothesis, experiments were set up at the Gezira Agricultural Research station with the existing Recommended Tillage System as a control. Initially, it was envisaged that the modified system proposed, when used sensibly on suitable soils, would be at least as good as the current system.

The key feature it is suggested, is to provide the germinating seed and seedling with enough water to grow without dehydration or, conversely, with a surplus of water causing waterlogging and lack of oxygen (Babiker *et al*, 1991). Seed-beds produced with a ridger, rather than with disc harrows appear to go some way towards meeting this requirement.

The Reduced Tillage System employing the ridger clearly showed improvement in soil physical properties in terms of bulk density and soil porosity compared with other treatments. Observation of aggregate size distribution on the soil surface following different tillage treatment showed slight variation which agrees with findings of Jaggi *et al*, 1972; Braunack and Dexter, 1988; Kacemi *et al*, 1992.

Bulk density and soil porosity showed significant variations between the tillage systems applied, agreeing with the fact that changes in bulk density and soil porosity depend on the amount of soil loosening done (Soane, 1975; Blake and Hartge, 1986; Ahmed and Haffar, 1993).

Soil penetration resistance is an effective method used in detecting zones of soil strength and the extent of tillage induced soil loosening or compaction and the degree of their persistence over time (Carter, 1988).

Over the period of the experiments, there were variations in values of resistance to penetration on the plots (mainly increased) at different depths, agreeing with the interpretations of some scientists, depending on the different soil conditions and treatments used (Mughal, 1973; Swain, 1975; Soane, 1975; Agrawal *et al*, 1975; Schindler and Muller, 1987 and Pelgrin *et al*, 1990). The results contrasted with the findings of Asoegwu (1987), who found that the presence of plant roots reduced soil strength at harvest time.

Of the different sowing methods used, drilling usually gave the best results. Babiker *et al* (1991) found that a seed drill with a tine furrow opener which placed seed at an average depth of 6cm gave the highest grain yield, compared to other methods of sowing. Also, they observed that broadcasting of seed under the Gezira conditions tended to be unsatisfactory because of bird damage, even when broadcasting was followed by disc harrowing. Also, for broadcasting, a higher seed rate is required (up to 180kg/ha) and many farmers find a need to re-broadcast after 2-3 weeks due to the failure of the crop to establish.

Ageeb (1992) and Elahmadi *et al* (1993) recommend that the sowing date for wheat under the Gezira conditions is between 12th and 26th November. They also recommend a seed rate of 50kg/f. In practice, most farmers increase the rate to 60kg/f in the belief that this will lead to a higher yield. The aim is for a count of 400 plants/m^2. Ageeb (1992) and Benaouda and Bouaziz (1992) regarded this density of plants as a major factor in successful wheat establishment. It is also eventually reflected in grain yield (Bansal *et al*, 1990; Ishag *et al*, 1991).

The results indicated that the shallow ridging only operation can be used successfully with a conventional seed drill at a lower seed rate than is common practice. Using a ridger and shallow cultivation also results in the cost of establishment of the crop being much reduced. The results obtained from the use of different implements are in accordance with the findings of Cary and Rasmussen (1979); Dawelbeit and Salih (1992); Dycder and Bourarach (1992) and Ahmed and Haffar (1993), who found considerable variations in machine performance when comparing different tillage practices. This was considered as being primarily due to the measuring techniques and instrumentation used.

The Reduced Tillage System, employing the ridger, showed improvements in soil physical properties and enhanced germination which was reflected in increased grain yield. The shallow cultivation was considered to reduce soil water evaporation and the lower weight of the ridger and tractor to reduce soil compaction when compared with the conventional system using a disc harrow. The disc harrow also required three to five passes to produce a seed-bed for wheat production, resulting in a higher cost.

The constraints that exist indicate that the most obvious improvement in grain yield might be achieved through modification to the seed-bed preparation process. This research programme has shown that there is potential for using the Reduced Tillage System employing ridging alone at a shallow depth of 5 - 7.5cm and drilling at a lower seed rate. This results in lower costs, a lower level of skill being required by the operator and a higher rate of work when compared with the traditional cultivation systems used for flood irrigated wheat production under the semi-arid conditions of North Africa.

A point against the use of a ridger which has to be considered is the possible problem of smearing, so subsoiling may be required every five years. This is, however, an improvement on the use of disc harrows which may lead to subsoiling being required every three years.

A major factor to consider is the likely adoption of the new concept by farmers (as discussed in the last section). Small farmers generally resist change and do not easily accept new ideas, particularly ideas which make drastic changes to long-standing existing practices, because of their traditional or conservative attitude towards life (Van den Ban and Hawkins, 1988). However, the simple approach to cultivation, using implements already available in the area, is thought likely to be acceptable.

The Agricultural Bank and Co-operative Groups have become very active in encouraging small farmers to purchase general purpose, medium sized four-wheel drive tractors of 50-60 engine hp; such a tractor would be very satisfactory for pulling a multi-ridger.

Results were obtained from two sites, Sudan and Morocco, each following one year's experimental work. These locations gave the opportunity to compare the similarity and variability of the different treatment/year, treatment/place and treatment/treatment interactions. Weather data from the two locations helped to confirm that the treatment/places interactions was the most significant effect, as discussed earlier (1.4.1).

Further investigation should be made on these effects before any practice can be recommended for adoption. The hypothesis has not been proved beyond doubt, but the following can be concluded. There are several aspects of this study that are of significance.

- The ridger had the better potential in that it could be possible to use it in a simple operation on a range of soil types at a shallow depth.

- The ridger could be combined with a levelling operation and/or drilling.

- The ridger could produce a sufficiently fine seed-bed for satisfactory crop emergence at a lower cost and a higher rate of work than the current practice using the conventional Recommended Tillage System.

- If the ridger is used in conjunction with a furrow system of distributing water within the established crop, it is also likely to lead to the more efficient use of irrigation water.

10.5 Suggestions for Further Work

There would seem to be four distinct areas where further work is suggested:

1. A repeat of the experiments conducted for one year only, in order to ascertain whether or not the results are repeatable, repeatability being the ultimate test of success. This work could be carried out either in Sudan or Morocco, but the shortage of technical resources in Sudan should be borne in mind. This work could be done on the state research stations, and the writer is confident that the value of the results obtained would compensate for the cost of the experimental work involved.

2. Field experiments to test the effects of soil aeration on water distribution and water use efficiencies associated with nutrient movement when using the alternative approaches of the disc harrow and the ridger. This work should provide answers to sources of the variation in yield across plots where flooding irrigation is used and also provide guidance on the distance between water furrows for optimum efficiency of water use. It would be necessary for this work to be carried out in Sudan or Morocco and again, there may well be resource implications as there would be a need for fairly sophisticated instrumentation. The work could be done on a state or university research station.

3. It was also evident from the experimental work completed in 1992-1996 that uneven land surface resulted in uneven water distribution and it is recommended that a small trial be established to examine the effects of land levelling on the efficiency of flooding irrigation water. This should also yield useful evidence as to whether the cost of large scale work could be justified or not. Even on a small scale, there would be resource implications in the form of the need for a laser guided scraper. A possible problem here is that the fertile layer of soil in Sudan and Morocco is generally shallow, if scraping and levelling are used, infertile layers of soil are likely to be exposed. Also the problem of water flow is not simply local undulation, the general slope of the land is clearly another problem when using flooding irrigation. A major project of this nature would be very expensive and would require financial help from outside the Sudan and Morocco. A pilot investigation could be completed by the state or university research stations.

4. There is considerable potential for the design and development of a simple seed drill suitable for attachment to a Camara soil levelling device. This seems to be an obvious follow-on from the recently completed work. Such a unit would allow the operations of soil levelling, consolidation, seed sowing and seed covering to be completed in one pass, providing benefits in the form of reduced evaporation of soil water and the speeding up of the seed-bed preparation/drilling process so allowing better use of the limited time available for getting the crop into the ground in good conditions, an important point in crop establishment under a hot irrigated environment. Work on this development could be carried out virtually anywhere in the world until the proving stage which would be essentially required to be done under vertisol soil conditions. Once developed, such a device would be suitable for manufacture by local artisans in North Africa. The design, construction and proving against currently used equipment could form the basis of a project to be undertaken by a local Sudanese agricultural engineering post-graduate student.

A general common factor related to all the above points would be the need for co-ordination of the agricultural research stations and universities and consultancy from developed countries with experience of this type of work. It is inevitable that costs would be high by Sudanese standards and funding might be provided through aid from external sources. Unless financial and technical aid were available, the possibility of these projects being started would be virtually nil.

11.0 The potential for reduced tillage systems for wheat production under irrigated semi-arid conditions: with particular reference to the Sudan and Morocco.

11.1 Introduction

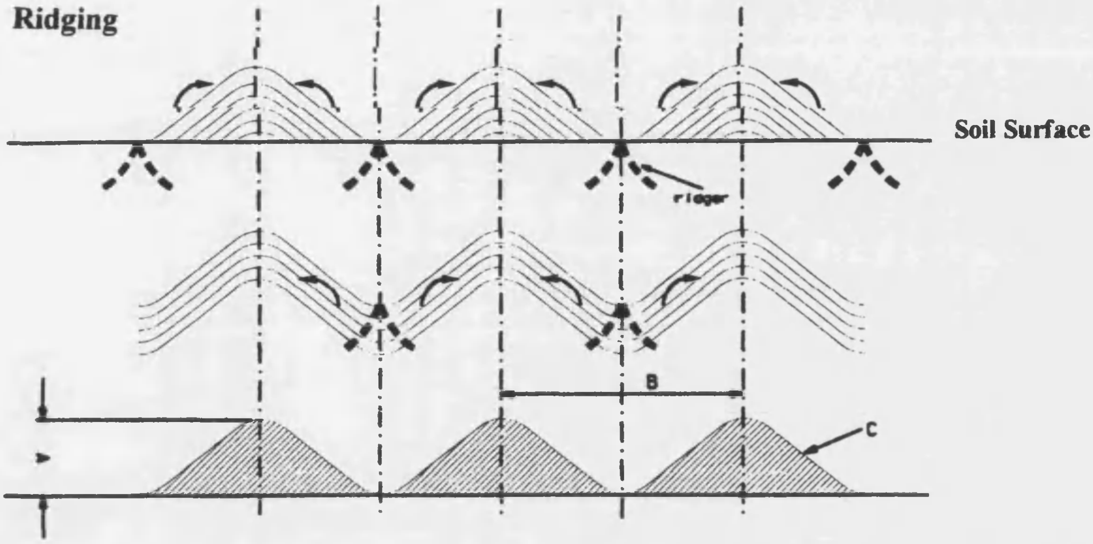
The average yield achieved by wheat farmers in the Sudan was 1.36 t/ha, only 6% higher than the average of 1.28 t/ha for the crop 20 years ago (Hassan and Faki, 1993). The most important factors affecting wheat production in the Gezira are seedbed preparation and crop establishment practices. (Babiker et al, 1991; Ageeb, 1992 and Hassan and Faki, 1993). On the heavy clay soils of the Central State of the Sudan, the different methods of land preparation, sowing and irrigation affect wheat establishment and directly caused low yields.

The tillage system recommended by The Agricultural Research Corporation (ARC) in Wad Medani is first disc harrowing during the rainy season. During September to October, at the end of autumn, a second cultivation would be done, again using a disc harrow. When the soil has a reasonable moisture content after the autumn this should be followed by a levelling operation. Mechanical planting is recommended using conventional seed drills or wide level disc type drills at 50 kg/f seed rate under the Gezira conditions. This system will be used as the control treatment as a part of the experimental programme. However, in Morocco the mechanisation of soil tillage in the semi-arid regions is not yet at a satisfactory level, especially on the heavy soils. Traditionally in Morocco, hand-broadcasting seeds of wheat and barley is common. There is a need for very high seeding rates of 175-350 kg/ha. The most commonly used implements are disc ploughs and disc harrows. They do not work effectively, often three to five passes being necessary to produce a fine structured seedbed at high costs. Also, conventional tillage makes soil vulnerable to erosion by wind and water. The more immediate unfavourable effects of repeated tillage are from moisture loss through excessive evaporation and soil compaction caused by tractor traffic, meaning poor crop establishment and sub-soiling probably being required every two to three years (Ryan et al, 1992). Dycder and Bourarach (1992) concluded that "for these reasons, there is a need for establishing new types of tillage systems which correspond to the pretensions of cultivation in semi-arid regions in quality of work as well as in efficiency".

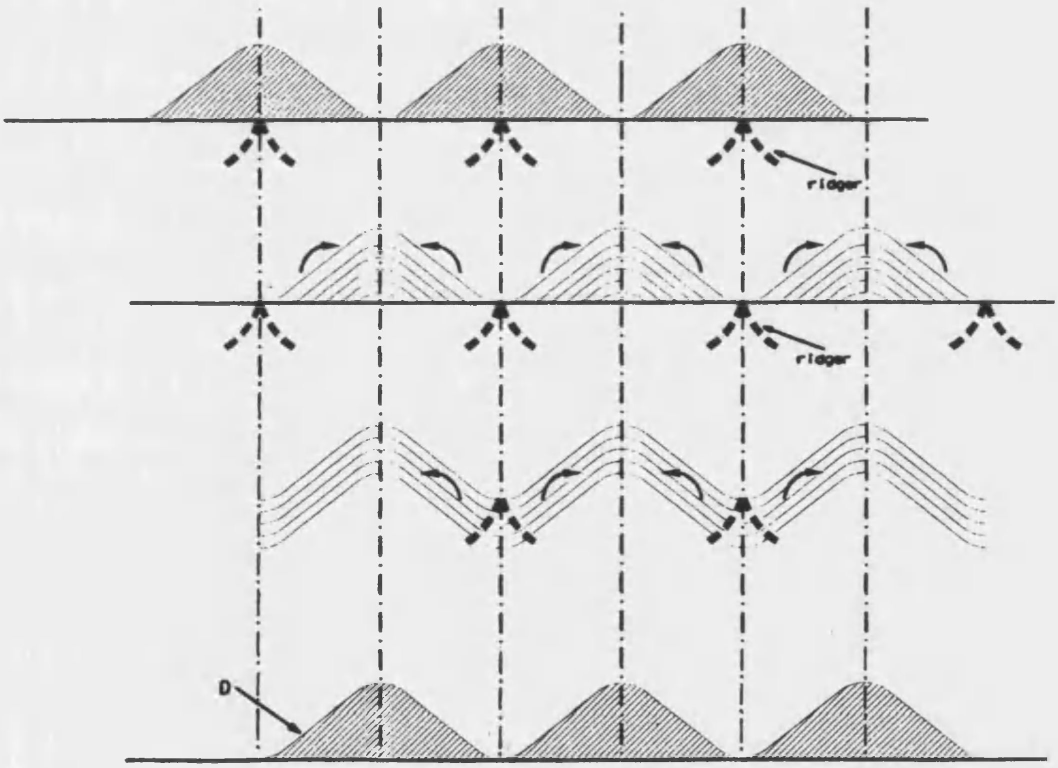
11.2 Reduced Tillage System

Various tillage systems are being adapted in wheat cultivation areas, which are dependent on the availability and cost of equipment. The reduced tillage system which is proposed as the basis for this study of wheat production under semi-arid conditions in the Sudan and Morocco by using a ridger, is readily available, is already used for vegetable production, and is easily made. The technique is ridging, followed by ridge splitting. A diagram of ridge dimensions for ridging and ridge splitting operations is shown in Figure 11.1.

[1] Ridging



[2] Ridge Splitting



A Ridge height 10-15cm
B Distance between centre line of ridges 40, 60, 80, 120cm
C Soil position after ridging
D Soil position after ridge splitting

Figure 11.1 A diagram of ridge dimensions, ridging and ridge splitting of Reduced Tillage System.

11.3 Soil Physical Properties
11.3.1 Soil Aggregate Sizes Distribution

The effect of five depths of disc harrowing on different mean weight of aggregate sizes which were determined after the first disc harrowing, and whose measurements were significantly different at 50 mm, gave a bell-shaped curve with a maximum at 17 cm depth. Naturally it is expected that the mean weight will increase the depth of disc harrowing in view of the increased tilled soil however, in the case of 50mm aggregate size it seems that the disc harrow crushed some of the big size aggregate after the 15cm depth. The results also showed significant differences at 40mm, 30mm and 20mm mean weight aggregate sizes, which increased linearly with increasing disc harrowing depth.

The results indicated that the second disc harrowing before sowing increased the mean weight of aggregate <10mm and reduced the bigger aggregate sizes. This may be attributed to the drying of the aggregate during the period between the two discing and also due to the second disc harrowing operation.

The results also showed that the second disc harrowing on aggregate sizes after sowing were significantly different at 20mm and 10mm. The mean weight of aggregate sizes increased linearly with the increasing depth of disc harrowing. Also the results obtained showed that <10 mm mean weight of aggregate size increased markedly in all five depths of disc harrowing. This probably was due to the low moisture content of the soil and further work done by the Camara levelling device and the seed drill. Braunack and Dexter (1989) found the aggregate sizes on the soil surface were influenced by soil type, soil moisture content and crop grown. The results obtained showed the effect of contrasting tillage treatments on aggregate size distribution on the surface with different implements and the resultant soil surfaces produced. In general, aggregate size distribution was measured as the mean weight-diameter of soil aggregates (Van Bavel, 1949). However, under semi-arid conditions, Kacemi et al (1992) emphasised that dry mean weight-diameter of aggregate was not significant among tested tillage systems.

Braunack and Dexter (1988) found that an intermediate size of aggregate (2-3mm) resulted in earlier emergence and higher wheat yields on clay soil than with larger aggregates (<4mm) on a loam soil. This is in agreement with Dorenko (1924) and Kvasnikov (1928), cited by Braunack and Dexter (1990) who reported maximum wheat yields with seed-beds of 2-3mm aggregates. This is in contrast with Jaggi et al (1972) who concluded that a seed bed of 1-2mm aggregates with a dry bulk density of 1.2-1.3g/cm3 would give the best wheat grain yield on a clay soil. Also, Braunack and Dexter (1988) found that finer aggregates (<1mm) tended to restrict aeration and reduced emergence under wetter soil conditions. It seems that soil structural adjustment (i.e. aggregate size control) is required in order to achieve this soil air/water/space balance and also to optimise the prevention of crusts. However, aerating generally increases the soil permeability and decreases the bulk density. Also, maximum contact between seed and soil for moisture imbibition and rootlet development are required together with ample consolidation to ensure good control over drilling depth. Weather variations affect cultivation by helping the natural drying/wetting cycles in aggregate size reduction. The first flooding irrigation applied on heavy soils in a hot environment aids soil breakdown; frequent flooding irrigation tends to restrict aeration and earlier emergence could be the result.

The results also agreed with the fact that the amount of soil loosening done under arid and semi-arid conditions is dependent on the different combinations of implements that are used (Mohamed Ali, 1991).

11.3.2 Soil Penetration Resistance

At a given depth of disc harrowing the penetration resistance increased with increase in the depth of penetration. These were significant differences in penetration resistance < 25cm the penetration resistance decreased with increase of depth of disc harrowing. This may be due to the increased reduction in the soil loosening with increased depth of disc harrowing. However, with penetration depths greater than 25 cm a similar effect of the 5 cm harrowed soil depth comes into play to conserve the moisture in the soil profile. This effect reduced the resistance of penetration to depths greater than 25cm in the 5cm disc harrowed plots. Whereas for 10cm disc harrowed plots the resistance of penetration increased due to decreased moisture content. Further reduction in penetration resistance values may be attributed to increased disc harrowing depth.

Results also indicated that at a penetration depth of 15 cm, penetration resistance values decreased with increase of disc harrowing depth. However, at a penetration depth of 50cm, the penetration resistance values increased with increase of disc harrowing depth. This may be due to the decreasing moisture content of the increased volume of roots. As the disc harrowing depth increased the volume of roots also increased and subsequently reduced the soil moisture content due to localised drying of soil in the root-zone.

At 13 weeks after sowing the impact of disc harrowing depth on penetration resistance became minimal due to soil setting.

The effect of the recommended and reduced tillage systems on soil penetration resistance values after the second irrigation generally indicate that penetration resistance increased with the increase of penetration depth. These results are in harmony with those of disc harrowing. However, the effect of seed rate did not depict a constant trend. Preliminary field observation indicated that generally the root system of wheat crop in vertisols under flood irrigation in the Sudan does not exceed 25cm depth.

The results also showed that the recommended tillage system gave a significantly greater penetration resistance at 25 cm depth of penetration, in comparison with the reduced tillage system using wide level disc type drill with ridges of 60 cm. It seems that the recommended tillage caused more loosening of the soil than the reduced one in view of a greater soil disturbance depth. However, the other whole penetration resistance values were not significantly different from each other. In the case of the reduced tillage system, the seed drill and wide level disc type drill on flat land resulted in significantly higher penetration resistance than the wide level disc with different ridges and beds. This may be due to increased soil disturbance caused by the ridger in comparison with sowing on flat land.

In the same experiment the effect of both tillage systems on penetration resistance at 8 weeks after sowing showed the impact of sowing methods, seed rates and penetration depths on penetration resistance values which increased with the increase of penetration depth.

In general the penetration resistance values 8 weeks after sowing under both tillage systems were greater than those at 2 weeks after sowing and this may be attributed to soil setting caused by intermittent wetting and drying cycles.

The influence of treatments on penetration resistance values at 13 weeks after sowing reflected similar trends and indicated more soil setting due to increased wetting and drying cycles. The results also showed that the effect of treatments on penetration resistance at 25cm depth for 8 weeks and 13 weeks after sowing were not significant.

These results were in agreement with that of Mughal, (1973) from Pakistan, working on black cotton soils. He found significant differences in the penetration resistance values between different depths of cultivation practices, however, the highest values were observed at 25-50 cm depth in tractor drawn tined cultivator plots.

The results also indicate that tillage operations decreased penetration strength, most probably because of soil loosening. This agrees with the findings that subsoiling to more than 45cm depth improved infiltration rate (Swain, 1975; Schindler and Muller, 1987). Results obtained, however, were contradictory to those of Wilkinson (1976), who reported that the infiltration rate of two tropical soils was found to decrease after ploughing and tillage operations.

Lowry et al (1970) tested the penetration resistance technique as an indicator of the mechanical properties of soils in relation to cultivation operations. They found that penetration resistance is one of the methods to evaluate soil structure. Today it is the most common system due to its facility and immediacy of data collected, its low cost and the independence of measured parameters from the terrain typology.

Under Moroccan conditions the reduced tillage practices and seed rates in relation to soil penetration resistance after the first irrigation showed significant differences. On all plots, penetration resistance values increased markedly up to 30cm depth and then more gradually at 40cm depth. The ridge splitting treatment showed considerable differences between seed broadcasting and seed drilling. This may be attributed to the presence of deep cracks in the shallow disturbed surface produced by the ridger and associated with the first application of excessive flooding irrigation after sowing, because much water was required to fill the soil cracks. At 8 weeks after sowing, on the plots of tillage practices associated with broadcasting and seed rates, there were highly significant differences in penetration resistance values, which were increased for different treatments with some variation in values at the upper layer of vertisols (20-30 cm depth). However, the same layer of soil with different drilling for different treatments had some clear variation in penetration resistance values with significant differences for the other depths, which were increased generally. This may be mainly attributed to the resettling of clay soil particles during subsequent irrigation. Also, the uneven accumulation of crop roots at 20-30 cm deep after two months.

At 13 weeks after sowing there were highly significant differences on plots of ridging and ridge splitting practices with sowing methods. The lowest value being obtained by the treatment of ridging only, with seed drilled at the lower seed rate. This was probably due to the more even distribution of plants on the surface following the use of the seed drill.

After the first irrigation, direct drilling showed a greater resistance to penetration at all depths, followed by the reduced tillage with variation in values at 25-40cm depth. This was probably due to the deep cracks and the shallow work of the ridging operation on the soil surface. Whereas conventional tillage at all depths resulted in the lowest values, due to the soil loosening at these depths and agrees with the findings of Soane (1975).

Over the duration of the experiment, direct drilling again showed higher resistance to penetration at different depths, followed by the reduced tillage treatment. At the layer of 20-30cm deep, reduced and conventional systems had differences in penetration resistance values. This may have been due to the effect of deep cracks on the reduced tillage plots as mentioned earlier and to the resettling of soil particles after subsequent irrigation for conventional tillage.

By the end of the growing season, direct drilling showed high values of resistance to penetration at all depths with both seed rates. However, conventional tillage came close to the reduced tillage treatment in the values of penetration resistance (because of irrigation water recompacting the soil). Sowing at 160 kg/ha always had greater soil strength, most probably due to the greater amounts of seed sown, resulting in a greater amount of crop roots, which in turn reduce penetration resistance. Conventional and reduced tillage systems at depths of 5-20cm resulted in similar soil strengths. This was probably due to the soil moisture content at the surface, attributed to the resettling of clay particles during subsequent flooding irrigation with the influence of tillage on soil moisture storage. The experimental site was fallow for the three previous years; however, different experimental plots may have received different amounts of water due to the undulation of the soil surface and different width of cracks.

Tom (1972) reported that Zeinelabedin and Robinson (1971), in a study of some Gezira soils in the Sudan, found that the width of cracks was affected by the length of the drying period, and by the type and clay content of the soil. They also found that the total volume of cracks in the upper layers of the Gezira vertisols they studied, were much affected by their recent soil cultivation history and vegetation present, such as grass and trees. The amount and frequency of rainfall also affected the amount of cracking that took place.

Pelgrin et al (1990) reported that soil penetration resistance, measured immediately after tillage application, was identical among tillage treatments in the upper 15cm, and significantly different between 15 and 40cm depth. They found that soil moisture content caused by flooding irrigation water affected the upper layer of the soil surface.

Tom (1972), in his study of the moisture content of vertisols in the Gezira, found that the maximum water holding capacity for the soil is over 60% and the optimum moisture range for plant growth is 36 to 40%; the lower limit of readily available water is 28% and at 23-24%, the crop is 'ruined' under semi-arid conditions.

11.3.3 Soil Bulk Density and Porosity

The soil bulk density values in the plots of reduced tillage treatments, ranged after sowing between 1.04 and 1.38 g/m^3 within the measured depths (0-36 cm depth).

At the beginning of the growing season, ridging and ridge splitting treatments at different depths showed no significant differences in bulk density and porosity. Over the duration of the experiment, ridging/ridge splitting with broadcast seed treatment resulted in a lower bulk density at the soil surface (0-12 cm depth). This was probably due to the greater soil disturbance and less soil compaction when manual broadcasting was applied. However, increasing bulk density influenced pore space by decreasing the average soil porosity at depths of 12-18cm and 18-24cm, which had slightly more compaction, probably caused by the presence of growing crop roots.

Soil porosity was always greater at the soil surface and that agrees with the fact that changes in bulk density and porosity are dependent on the amount of soil loosening done and soil moisture content. Also, this may be attributed to the influence of reduced tillage depth on soil moisture storage under semi-arid conditions. Culley and Larson (1987) and Nesmith et al (1987) found different results, in the light of higher bulk density values after harvested for no-till treatments, in relation to that of conventional tillage practices in the 0-10 cm layer. These contrasting results might be attributed to the effect of the soil type, intensity of the cultural practices and duration of the growing season.

Different tillage systems showed significant variation within different depths on bulk density and porosity. After sowing, the direct drilled plots had variable bulk density within different depths. This is probably due to the presence of trash and cracks in the undisturbed treatment plots. Over the duration of the experiment, direct drilling treatment showed variation of the bulk density and porosity within different depths. However, by the end of the growing season, all tillage systems generally showed increased bulk densities at different depths.

There were significant variations in bulk densities and soil porosity values below the depth of 18-24 cm. This was mainly attributed to the breakdown of soil aggregates on the surface during subsequent flooding irrigation and cumulative settling and packing of soil particles.

It seems that surface disturbance with reduced tillage at shallow depth, may cause the filling of soil cracks to some extent by pulverised soil from the ploughed layers above. This may also have contributed to higher bulk density values during the growing season, together with the settling of soil particles over the duration of the experiment due to the effect of flooding irrigation.

The warm, relatively humid climate of Morocco and the semi-arid vertisol soils may also influence the values of bulk density and soil porosity of the undisturbed surface of direct drilling treatment plots, compared with the other tillage treatments. The presence of deep cracks in the direct drilling treatment plots which closed after wetting and swelling, so reducing the pore space in soil, could also influence these values.

In general, at all depths, conventional tillage resulted in the lowest bulk density, followed by reduced tillage. This may have been due to the soil loosening at the cultivated depths. This agrees with the results found by Soane (1975) and further supported by Burnett and Tackett (1986), who found that four years after rototilling and three years after mixing with a ditching machine, the bulk density of the loosened soil was still lower than that at similar depths in conventionally tilled plots.

Several reports have indicated contrasting results from the effect of tillage on bulk density and soil porosity. Blevins et al (1983) reported that tillage had no effect on bulk density after a ten year period of tillage treatments on a medium textured soil. However, other researchers have reported a drastic increase in bulk density with no-till compared to mouldboard ploughing of a clay loam soil (Griffith et al, 1977; Gantzer and Black, 1978). Belvins et al (1985) found similar bulk density values with conventional and no-till systems and lower bulk density with chisel tillage on poorly drained soil. Pelgrin et al (1990) reported that bulk densities, measured three weeks after tillage operations, were similar in the upper 20 cm of a sandy loam soil where tillage was done with a disc plough, mouldboard plough, cultivator, disc harrow and no-till. They indicated that the bulk density values increased with time and were significantly higher in no-till, disc plough and cultivator than mouldboard plough and disc harrow.

11.4 Plant Parameters

11.4.1 Plant Population and Crop Development

Results obtained showed that there is no significant difference between different depths of disc harrowing on the emergence and development of crop at the five leaves stage. There were significant differences in plants/m^2, shoot dry weight and shoot: root ratio at the flowering stage for 10 cm depth.

It seems that the uneven emergence of plants/m^2 at two weeks after sowing was due to the lack of levelling and uneven distribution of water when flooding irrigation was applied. However, plants/m2 were improved at 5 leaves and flowering stages due to the subsequent irrigation and also the break down of surface clods, which allowed shoots to appear above the soil surface more easily.

There were significant differences for reduced and recommended tillage systems, sowing methods and seed rates at two weeks after sowing. The results obtained showed that reduced tillage with wide level disc sowing on 60 cm ridges with 40 kg/f seed rate treatment had slightly higher differences in plants/m2, whereas seed drill – 20 cm on flat land with 60 kg/f seed rate treatment gave the highest values on shoot dry weight (g/m2) at two weeks after sowing. This was nearly 30% higher compared with the other different sowing methods and seed rates. The differences between the other treatments were slight. This was probably due to more soil moisture after the first flooding irrigation on the flat drilling treatment.

However, seed drill – 20 cm on flat land with 40 kg/f seed rate treatment gave the highest values on root dry weight. this was possibly due to the fact that at the emergence stage (only two weeks after sowing) seedlings were small and it was difficult to distinguish the beginning of stems.

Pande and Bhan (1966), Mech et al (1967) and Mahmoud (1985), found that deep ploughing to depth of 28 cm or more has an influence on crop growth due to its effect on soil structure. This is an absolute contrast under the Gezira conditions, due to the shallow fertile layer and the high cost of the deep cultivation required. Also wheat roots are usually only at shallow depths.

Under Moroccan conditions, different practices of reduced tillage system and sowing methods showed significant differences within several weeks of sowing on plants/m^2. This was possibly due to the different sowing methods and amount of surface disturbance.

In the second week after sowing, the broadcast treatment had a higher number of plants/m2. It seems likely that this was due to the presence of seeds at shallow depths compared to the seed drilled at a depth of 5 cm, which needed more time to emerge.

In the third week after sowing, the ridging treatment with lower seed rate had a higher number of plants/m^2 with both sowing methods. This indicates that the ridging alone, at shallow depth, may have achieved a suitable condition for emergence.

At the ninth week after sowing, seed drilled at the lower seed rate resulted in more leaves per main stem of plant. This may have been due to the even distribution of sowing, with the seed drill and may also be dependent on the variety of wheat (Achtar G2). However, employing a ridging treatment with seed drilled at a lower seed rate always resulted in more stems per plant. This was possibly due to a more even distribution of seeds under the surface.

The reduced tillage system always resulted in more plants/m2 during the period of experimentation, compared with conventional tillage and direct drilling, which were always less than 300 plants/m2. The maximum population, with reduced tillage was 349 plants/m2. However, after the fifth week of sowing, there was a reduction of about 15 plants/m2, probably due to the uneven distribution of irrigation water.

Different tillage systems at different seed rates showed significant differences in the total number of leaves per main stem of plant during the twelve weeks after sowing. This may be due to the amount of soil loosening and the beginning of the tillering stage of the wheat, which usually starts after the fifth week following sowing.

Reduced tillage always resulted in more stems per plant between seven and twelve weeks after sowing, while the other tillage systems showed significantly lower numbers.

Results showed that reduced tillage also resulted in a higher number of leaves per stem and each stem attained 7.0 leaves, compared with conventional tillage and direct drilling, with 5.6 and 5.0 leaves per stem respectively. This may be due to the favourable soil surface disturbance caused by the ridging operation, compared with the deep cultivation and no-till treatments.

Benaouda and Bouaziz (1992) surveyed fields in the Chauoia region of Morocco and reported that the grain yield was very much dependent on the emergence rate, which determines the initial stand. The best yield was obtained by an initial stand of 400 plants/m^2. Above or below this limit, the yield decreased. However, the seed losses during crop establishment were mainly due to mechanical obstacles at the soil surface and were the result of seed-bed preparation during inappropriate soil conditions such as when it was too wet. The farmers, well aware of these losses, compensate by using higher seeding rates to obtain adequate stands.

Results showed that a lower seed rate produced a greater number of plants/m^2 (approximately 300 plants/m^2). The reason for this is not clear, but it may be attributed to the fact that a reasonable number of seeds at the lower seed rate found favourable environmental conditions. The pronounced effects of the ridging operation as a reasonable surface disturbance may have an influence on wheat growth during the first part of the growing season. Mahmoud (1985) and Meek et al (1988), found that different soil disturbance had an influence on crop growth due to its effect on soil structure.

11.4.2 Yield and Components

The effect of different depths of disc harrowing on yield and components was not significant. The highest yield appeared to be with 10 cm depth of disc harrowing.

Reduced tillage system gave the highest value on the number of grains per head with wide level disc sowing at 60 kg/f seed rate, while the same treatment gave a slightly lower value of 40 kg/f. This possibly was due to the better depth of sowing with wide level disc type drill which sown at 7 cm depth with the high seed rate level.

However, there were no significant differences on yield and components with other different treatments.

Under Moroccan conditions, reduced tillage in interaction with sowing methods and seed rates reflected on grain yield. Highest yields were obtained from drilling at 140 kg/ha followed by broadcasting at 160 kg/ha.

Reduced tillage showed the greatest number of ears/m² followed by direct drilling. The conventional system showed lower ears/m², which may be due to the vertisol's compaction following continuous use of conventional tillage implements.

Reduced tillage at a lower seed rate resulted in a considerably better grain yield compared with the other tillage systems. Furthermore, ridging only, with seed drilled at a lower seed rate, resulted in a higher grain yield. It seems that the ridging operation at shallow depth could have contributed to the well-developed root systems. Generally, most roots of the wheat crop are at the shallow depth; it may be that the enhanced nutrient and water uptake resulted in increasing ears/m2 which, in turn, was reflected as a higher yield.

11.5 Machine performance and field operation costs

Regression analysis showed there were no significant relationship between different disc harrowing speeds and mean weight of different aggregate sizes produced on the surface layer at 10 cm depth after the first disc harrowing. This was probably due to the low soil moisture content (5.6%) under the Gezira conditions. However, clod breakdown could be achieved with the benefit of natural conditions leading to weathering and irrigation water. Results also showed that increasing the depth of disc harrowing caused increased power requirement and cost. Cost is very considerable and was caused by the high cost of diesel fuel and running cost of the tractor. However, the grain yield slightly increased at 15 cm and 20 cm depths, while the best yield was obtained at 10 cm depth. This 10 cm depth of cultivation could be achieved by the practices of the reduced tillage system (ridging and ridge splitting) using an ordinary ridger and makes use of a readily available implement which is used for other operations (See Table 11.1).

However, results indicated that the reduced tillage system was achieved at a minimum cost. The cost was approximately one half of the tillage system of disc harrowing twice that is recommended by the Agricultural Research Corporation at Wad Medani, Sudan, which also requires more skill from the operator.

Table 11.1 Power requirements and field operation costs of different implements in the Sudan (Season 1993/94).

Equipment and Operation	Power Requirement (Draught Force) (kN)	Fuel Consumption (1/ha)	Field Capacity (ha/h)	Operation Cost (LS/ha)
First disc harrowing (at 10cm depth - 1.8m wide)	750	5.31	1.7	1320.0
Second disc harrowing (at 10cm depth - 1.8m wide)	700	4.92	1.9	1190.4
Ridging (10-15cm depth – 1.8m wide)	350	4.48	2.1	730.3
Ridge Splitting (10-15cm depth – 1.8m wide)	328	4.27	2.6	675.1
John Deere-8200 Seed drill (5cm depth - 3.0m wide)	320	4.28	1.8	814.9
Nardi Wide Level Disc typedrill (7cm depth - 3.0m wide)	315	3.75	2.2	712.0

£1 = LS 510 (1993)

Results also showed that the wide level disc type drill required a lower draught force, had a lower operation cost and also a higher field capacity compared with the conventional seed drill which was slower in turning.

Under Moroccan conditions with the use of an Autotronic Massey Ferguson – 3080 tractor, equipped with a Lax 55 multi purpose intelligent digital data logger and a central processing unit to measure machine performance for different implements was used in the field operations (See Table 11.2). The results showed that the disc plough required a higher draught force and a lower forward speed; the seed drill required a lower draught force and could work at a higher speed. The disc harrow required about half the draught force of the disc plough and was higher in operation speed, this being mainly due to the difference in working depths. The disc plough and disc harrow are traditional Moroccan tillage implements and require a high power input to operate.

Direct drilling is a relatively new concept in Morocco and so far has only been used in experimental situations. This is due to the cost of the machine, the high power requirement, problems with weeds and the limited availability of this equipment (Bahri and Bansel, 1992).

The direct drill required a much higher draught force, this mainly being due to the weight of the drill and the penetration operation of the disc coulters on the untilled soil surface for the sowing process. The direct drill had a higher work rate, this being due to the operating width of 3.0 m. The direct drill also had a high power requirement. The actual power required is dependent on the equipment width, working depth and field conditions.

The difference between forward speeds of the semi-mounted direct drill and the conventional seed drill was less than 1.0 km/h and generally, the trailed seed drill was slower in turning, which directly reduced the work rate. This is an important factor during the agricultural season in semi-arid regions due to the short sowing period, rainfall and limited availability of machines between farmers.

The lowest draught forces were associated with the ridging and ridge splitting operations.

Other field operations showed that ridging followed by ridge splitting and drilling with the conventional seed drill required much less power at the same constant operational speeds.

Fuel consumption was higher with the disc plough, mainly due to the high amount of soil lifting. However, a lower fuel consumption was observed with the ridging/ridge splitting process and the conventional seed drill. However, the Autotronic tractor used for the test in the field has an engine of 92 hp, which requires more diesel for running; in practice, it would be possible to use a lower powered and therefore more economical tractor.

Table 11.2 Machine performance and field operation costs of differen implements in Morocco (Season 1994/95).

Equipment and Operation	Forward Speed (km/h)	Draught force (kN/m)	Power requirement (kW/m)	Fuel Consumption (l/ha)	Field Capacity (ha/h)	Operation Cost (Dh/ha)
Disc plough (25-30cm depth - 1.5m wide)	1.99	21.75	8.01	22.6	0.89	789
Disc Harrow Twice disc harrowing at (10cm depth - 1.8m wide)	2.10	12.44	4.02	13.10	1.13	640
Ridging (10-15cm depth - 1.8m wide)	4.5	4.11	2.85	10.20	1.68	266
Ridge Splitting (10-15cm depth – 1.8m wide)	5.1	3.80	2.98	9.10	2.25	204
Conventional Seed drill (5cm depth - 3.0m wide)	6.6	3.27	1.99	9.80	1.96	217
Direct Drilling (5cm depth - 3.0m wide)	6.0	9.80	5.44	11.50	1.51	893

£1 = Dh12.9 (1995)

Field operations confirmed that increasing the depth of cultivation with conventional tillage (disc plough and twice disc harrow) mainly caused increased power requirements and cost. A skilled operator is required to achieve a good standard of ploughing and harrowing and this is also increases the cost.

The costs of operating the different equipment were considerable, being caused by the high cost of diesel fuel and the running cost of the tractor. The conventional tillage system showed the highest power requirements and overall, the highest operating costs and a lower work rate, followed by the direct drilling which had a work rate of 1.51 ha/h. Much of the operation cost is due to the basic cost of the machine.

The reduced tillage system employing the ridger clearly shows the lowest cost of operation and had a higher work rate. Even when ridging is followed by ridge splitting, the cost is still considerably lower. Reduced tillage combined with the drilling operation could reduce the cost by a half compared with direct drilling. The cost of the reduced tillage system was also approximately a third of the cost of the conventional system.

Other considerations with the conventional system are the availability of tractors and implements. This is due to the shortage of machinery available to farmers. The conventional practice also has a lower rate of work and requires more skill from the operator.

Dycder and Bourarach (1992) also found significant variations in their results obtained, when assessing machine measurements for different implements among different treatments under Moroccan conditions. They emphasised that there are also significant differences in field operation costs, depending mainly on the type of equipment and its availability during the growing seasons.

The results obtained here are also in accordance with the findings of Cary and Rasmussen (1979) as well Ahmed and Haffar (1993), who found considerable variations in the machine performance for a comparison between different tillage practices.

A comparison of the conventional tillage system and the proposed reduced tillage system is shown in Figure 11.2.

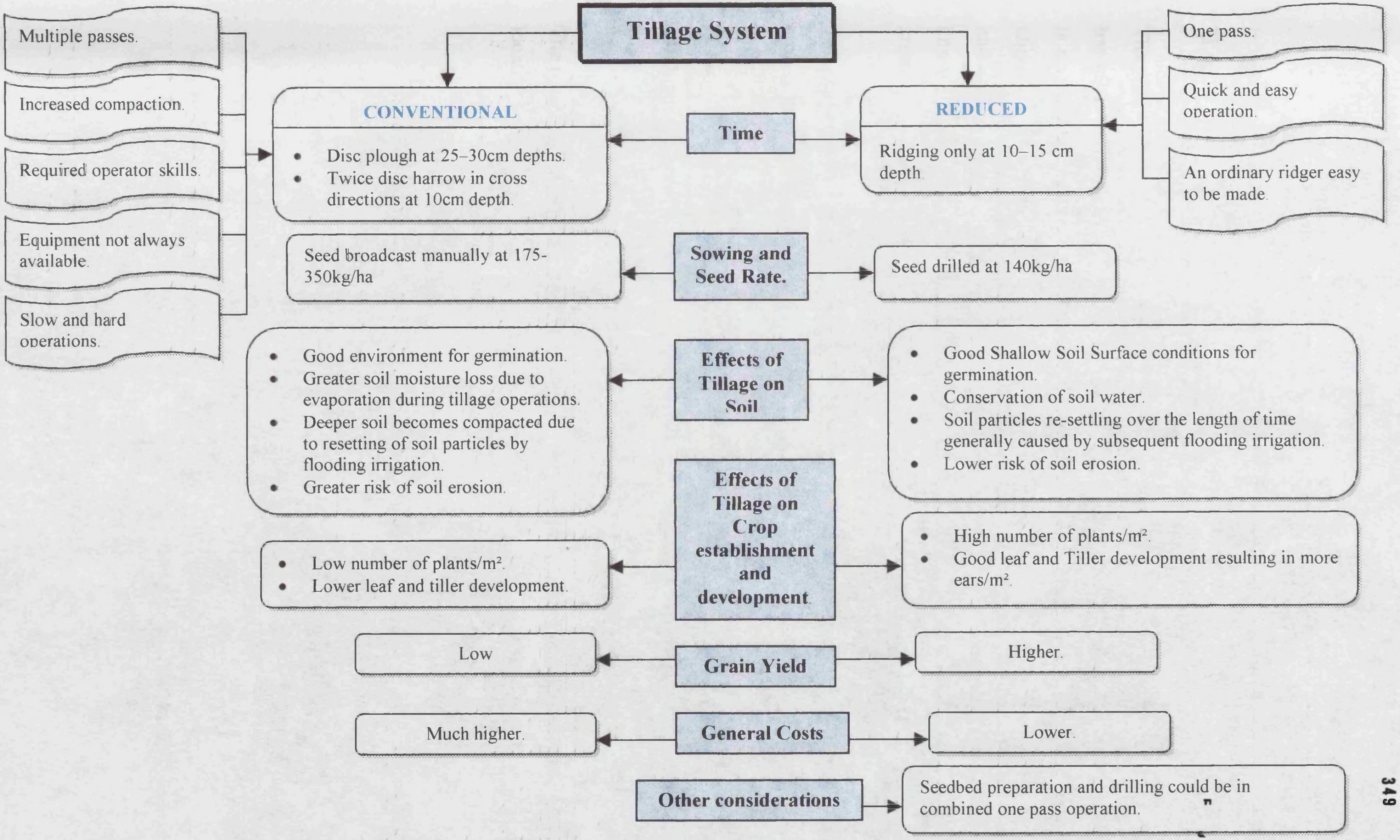


Figure 11.2 **Comparison diagram of tillage systems used in semi-arid conditions with flooding irrigation.**

11.6 Conclusions

The desire to grow wheat on an increased scale in Sudan and other countries in North Africa has meant that attempts are being made to cultivate it in areas such as the Gezira, where it is not a 'traditional' crop. Wheat is being grown on soils which are not ideal for it, in climates for which it is not well suited and by farmers who lack experience of the cultivation and irrigation techniques required. Also, in these countries, lack of materials, equipment and knowledge based on scientific investigation is common, so it is inevitable that problems will arise.

The problem with a short-term crop such as wheat is that if the establishment phase of the crop cycle is not successful, the low initial plant population is unable to tiller and spread sufficiently to yield satisfactorily. It follows, therefore, that the early stages of establishment of the crop are critical. The supply of water is also critical throughout the life of the crop, although there is probably more latitude for uneven distribution later in the growing season, when the root system has developed, than during the seed/seedling phase.

The results obtained from the experimental work completed in 1992-1996, conducted at two locations in the Semi-arid regions of the Sudan and Morocco showed that:

- The Reduced Tillage System improved soil physical properties, the mean weight of 30mm clods on the soil surface was reduced by 7% and penetration resistance at 25cm was reduced by 8%.
- Crop establishment at 2 weeks after sowing was improved by 40% and the number of leaves/plant at 12 weeks after sowing by 35%.
- Yield of grain was improved by 39%.
- The work rate during seed bed production (1.8m disc harrow : 1.8m ridger) was improved by 32% and the overall cost of producing the seedbed was reduced by 76%.
- Fuel cost for seedbed production was reduced by 22%

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APPENDICES

Table 1 Sudan: climate classification (Source: Craig, 1991)

Climatic type	Annual rainfall (mm)	Wet months	Seasonality index	Other climatic characteristics	Agriculture
Tropical Continental Desert	<200	<0.5	≥1.25	Relative humidity always <40%. Very short summer wet season in south. Large diurnal and annual temperature range	Nomadic pastoralism. Cultivation only via irrigation along Nile and Atbara
Red Sea Desert	<200	<0.5	1.10–1.25	Relative humidity >40% throughout year. Winter rainfall maximum. Smaller temperature ranges	Nomadic pastoralism
Tropical Semi-Arid	200–500	0.5–1.9	1.10–1.25	Highly variable annual rainfall	Widespread cultivation by dry farming, but frequent crop failures
Jebel Marra mountain climates	>500	≥2.0	1.10–1.25	Mean annual temperature <25 °C. High diurnal range. Increase in rainfall with altitude	As Sub-Humid, but also citrus fruits, vegetables and potatoes
Tropical Sub-Humid	500–800	2.0–3.9	0.90–1.15	More reliable annual rainfall for dry farming crops	Widespread cultivation; more reliable crop production. Zone of major mechanized farming
Tropical Wet-Dry	800–1200	4.0–5.9	0.60–0.90	Long dry season and long wet season	Cattle rearing dominant. Some millet cultivation
Tropical Rainy	>1200	≥6.0	<0.60	Short dry season. Warmest months are in 'winter' dry season. Very low annual temperature range	Maize and eleusine. Coffee, tea plantations. Some fruits of the wet tropics in mountains

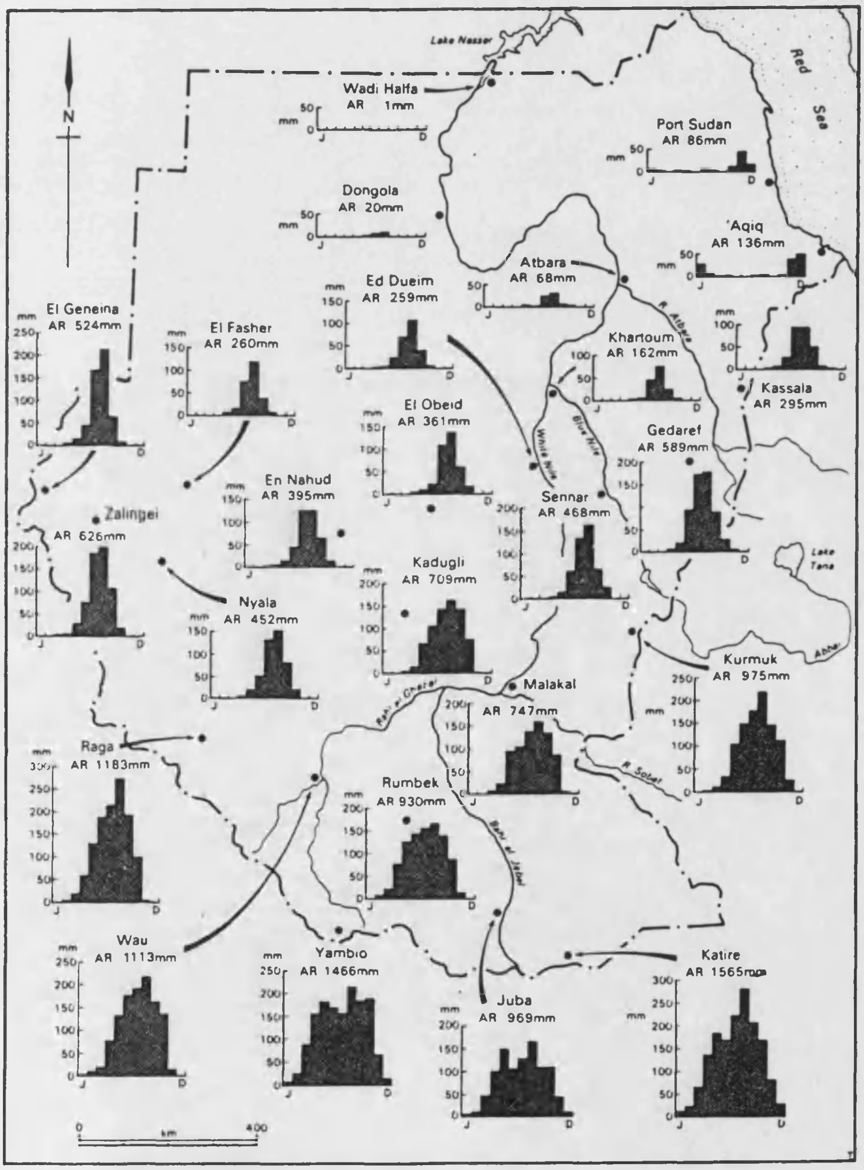

Figure 1 Sudan: rainfall regimes at twenty-five representative locations, 1951-80.
AR = mean annual rainfall

(Source: Craig, 1991)

Table 2 Some chemical parameters of the soils on the experimental site (Gezira Station 1993).

Parameters	EC		SAR		ESP		PH	N %	O.C. %	P %	CEC %	Ca Co_3%	K %
Depth (cm)	0-25	25-100	0-25	25-100	0-25	25-100							
	0.76	2.17	4	9	10	21	7.7	0.043	0.386	3.53	53	3.7	0.97

Table 3 Mechanical analysis of the soils on the experimental site (Gezira Station 1993).

	Particle Size Distribution %			
Texture	Coarse Sand	Fine Sand	Silt	Clay
Clay	7%	6.9%	25%	61%

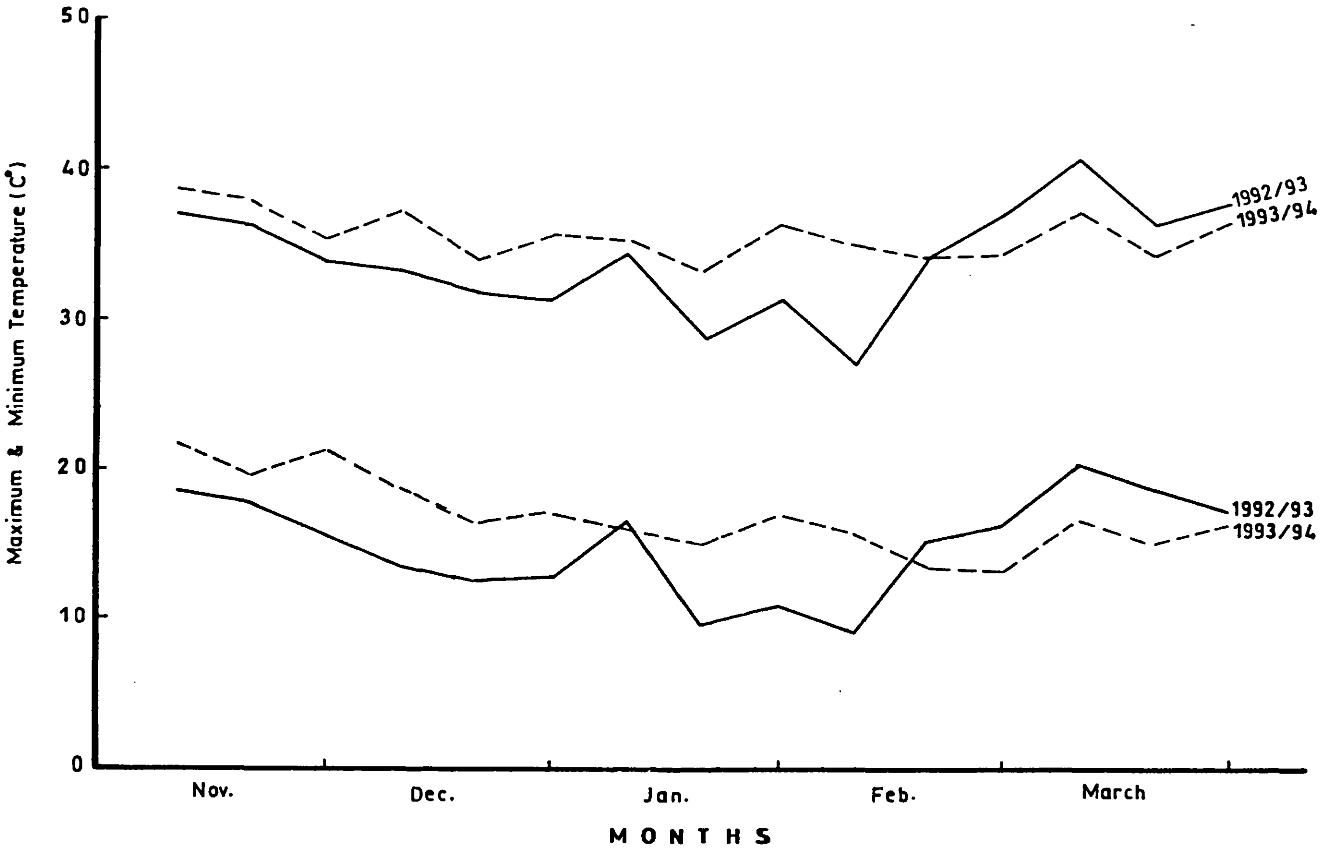

Figure 2 Maximum and minimum temperature during growing season (on ten days average) Gezira Station 1993/94.

Regressions of mean agregate weight against speed

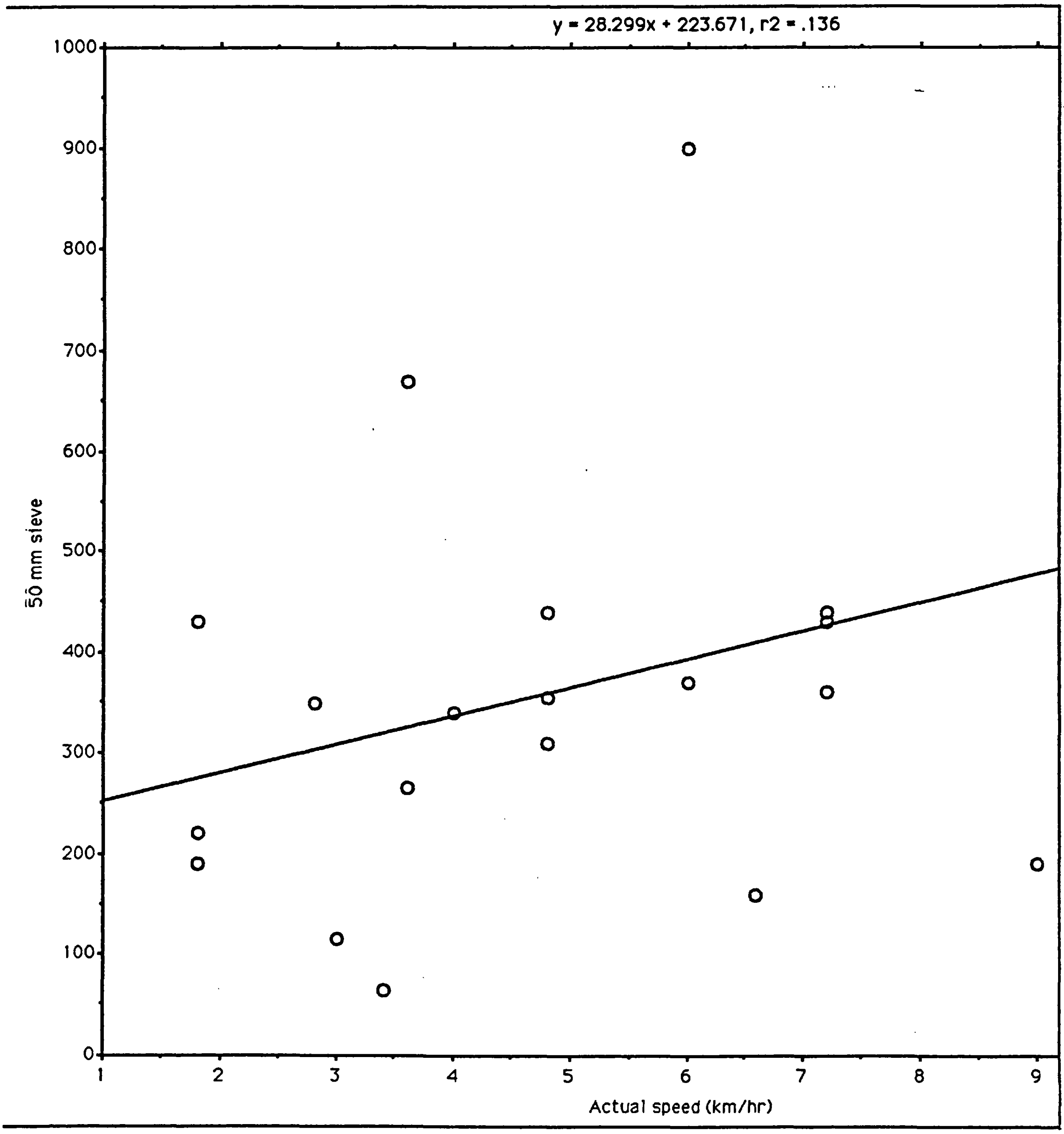

Figure 3 Effect of different forward speeds of the first harrowing on the mean weight of 50mm aggregate size distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

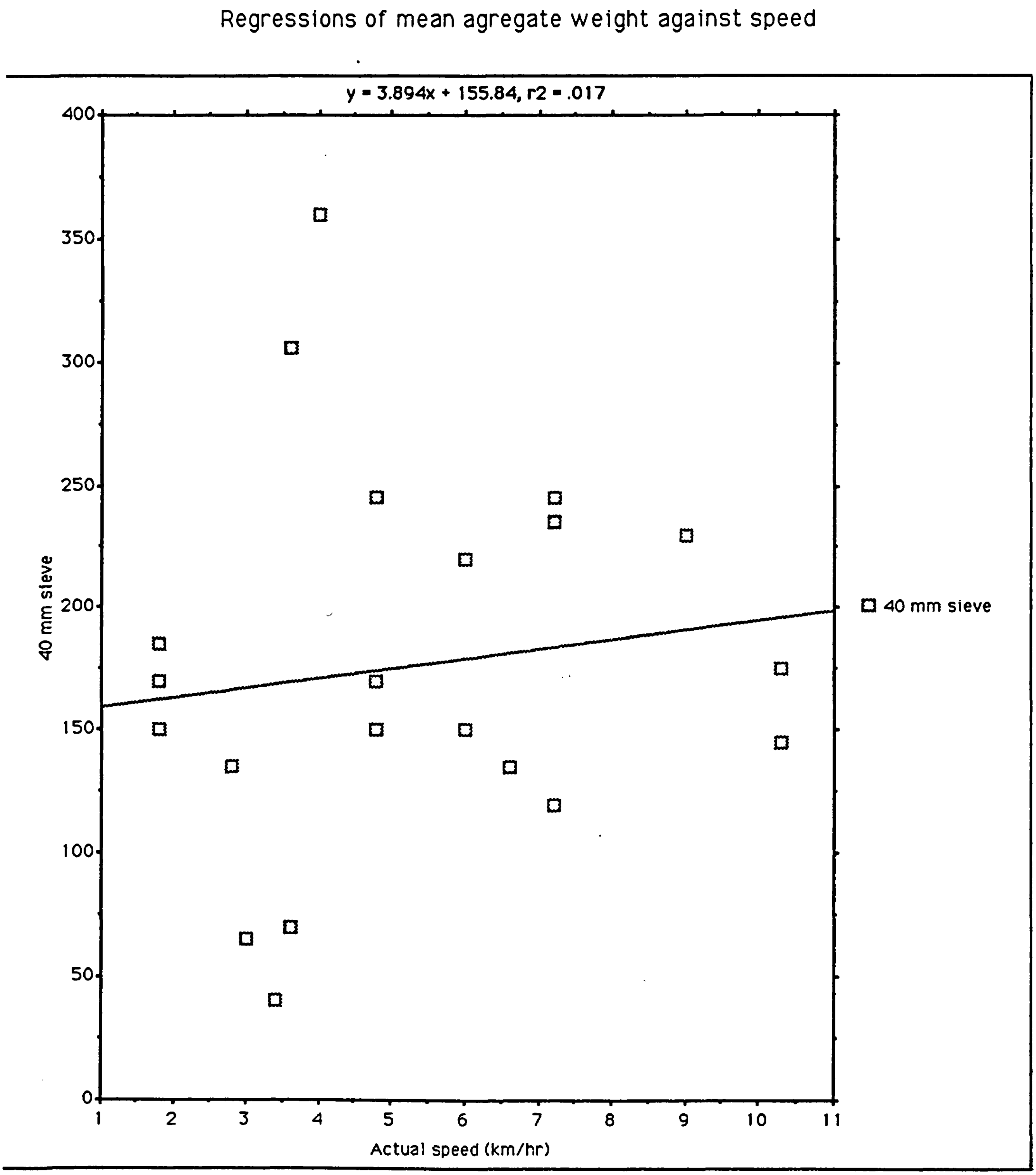

Figure 4 Effect of different forward speeds of the first harrowing on the mean weight of 40mm aggregate size distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

Regressions of mean agregate weight against speed

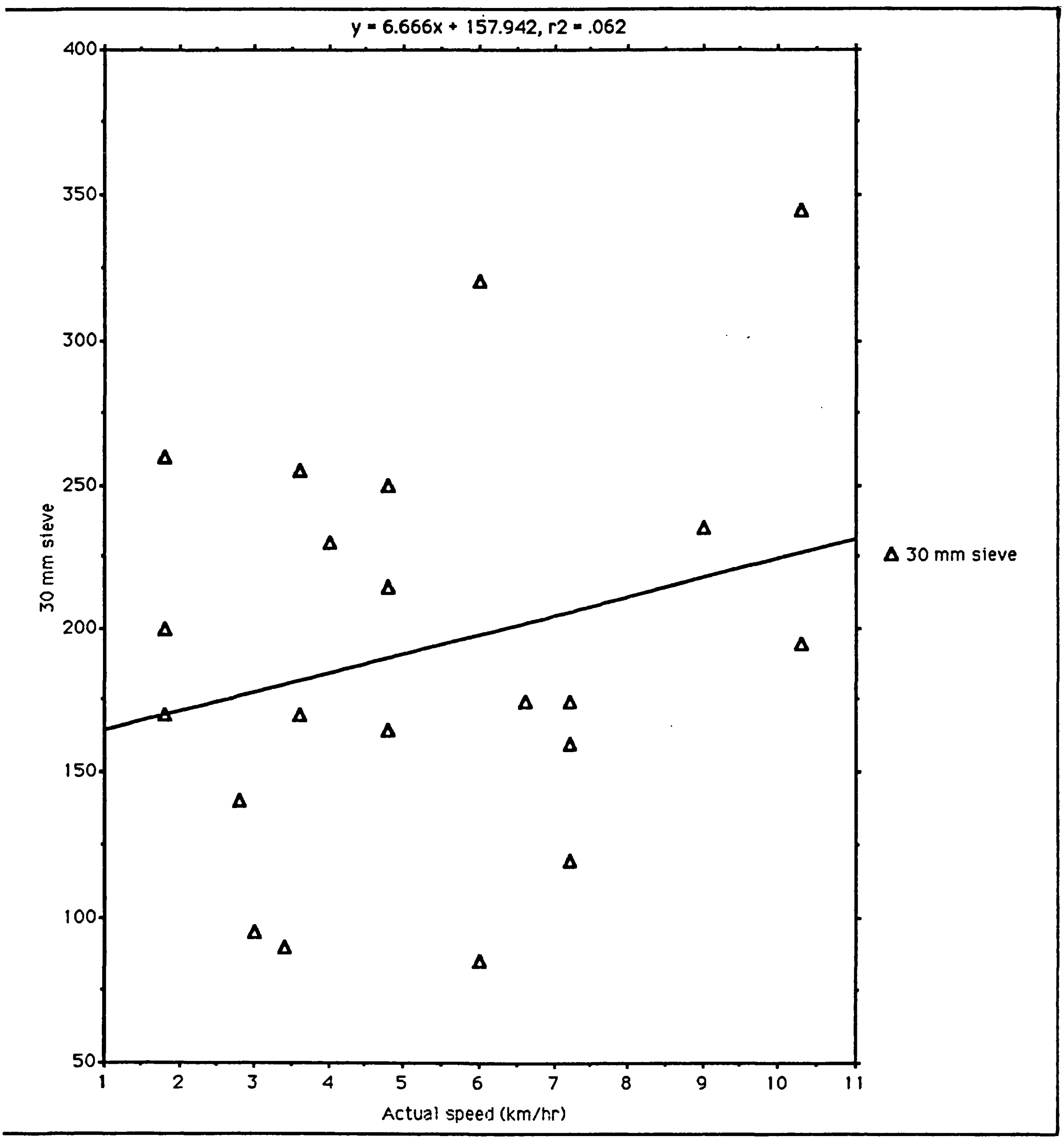

Figure 5 Effect of different forward speeds of the first harrowing on the mean weight of 30mm aggregate size distributed on soil surface (m.c. = 5.6%) Gezira Station 1993.

Regressions of mean agregate weight against speed

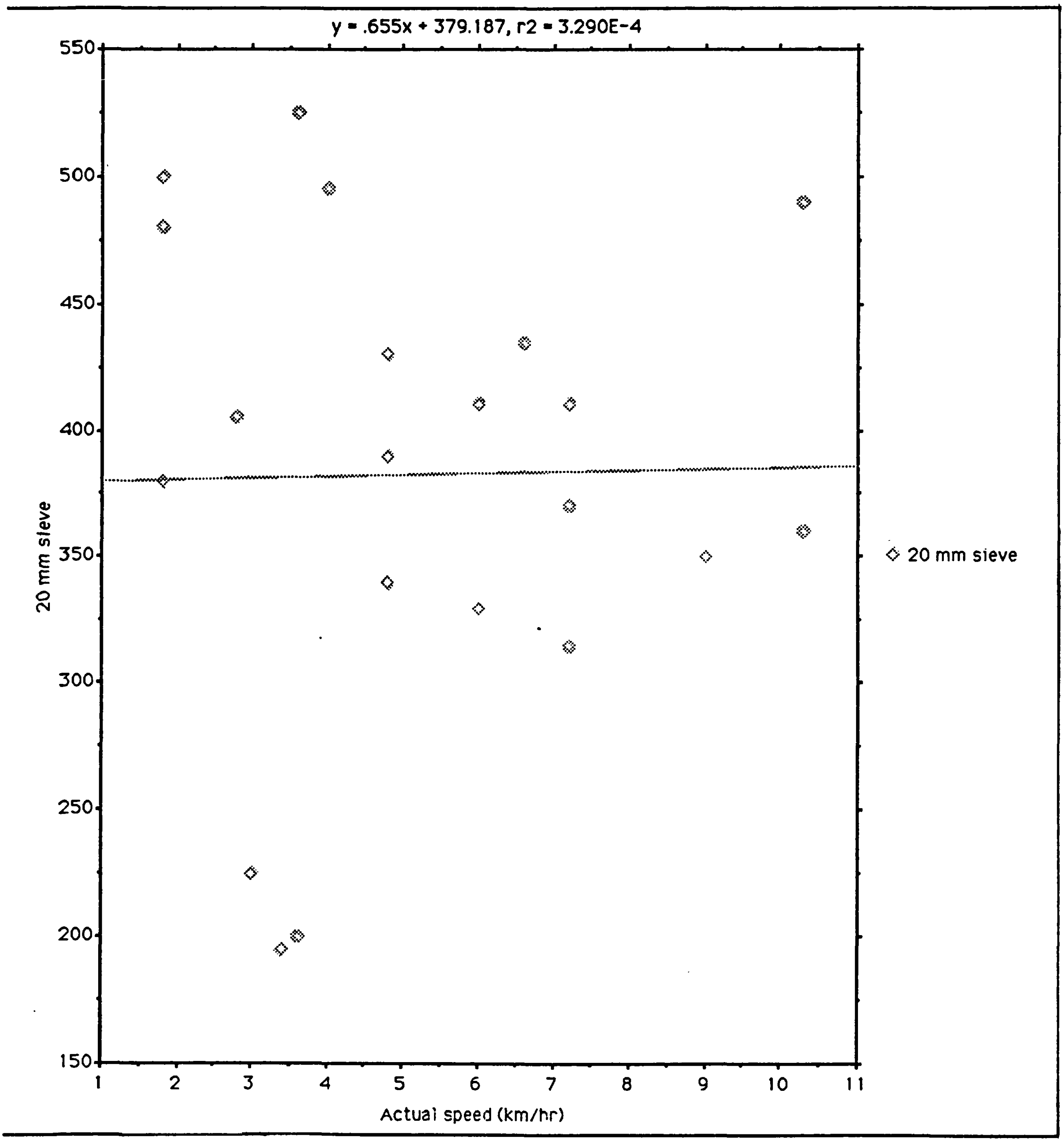

Figure 6 Effect of different forward speeds of the first harrowing on the mean weight of 20mm aggregate size distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

Regressions of mean agregate weight against speed

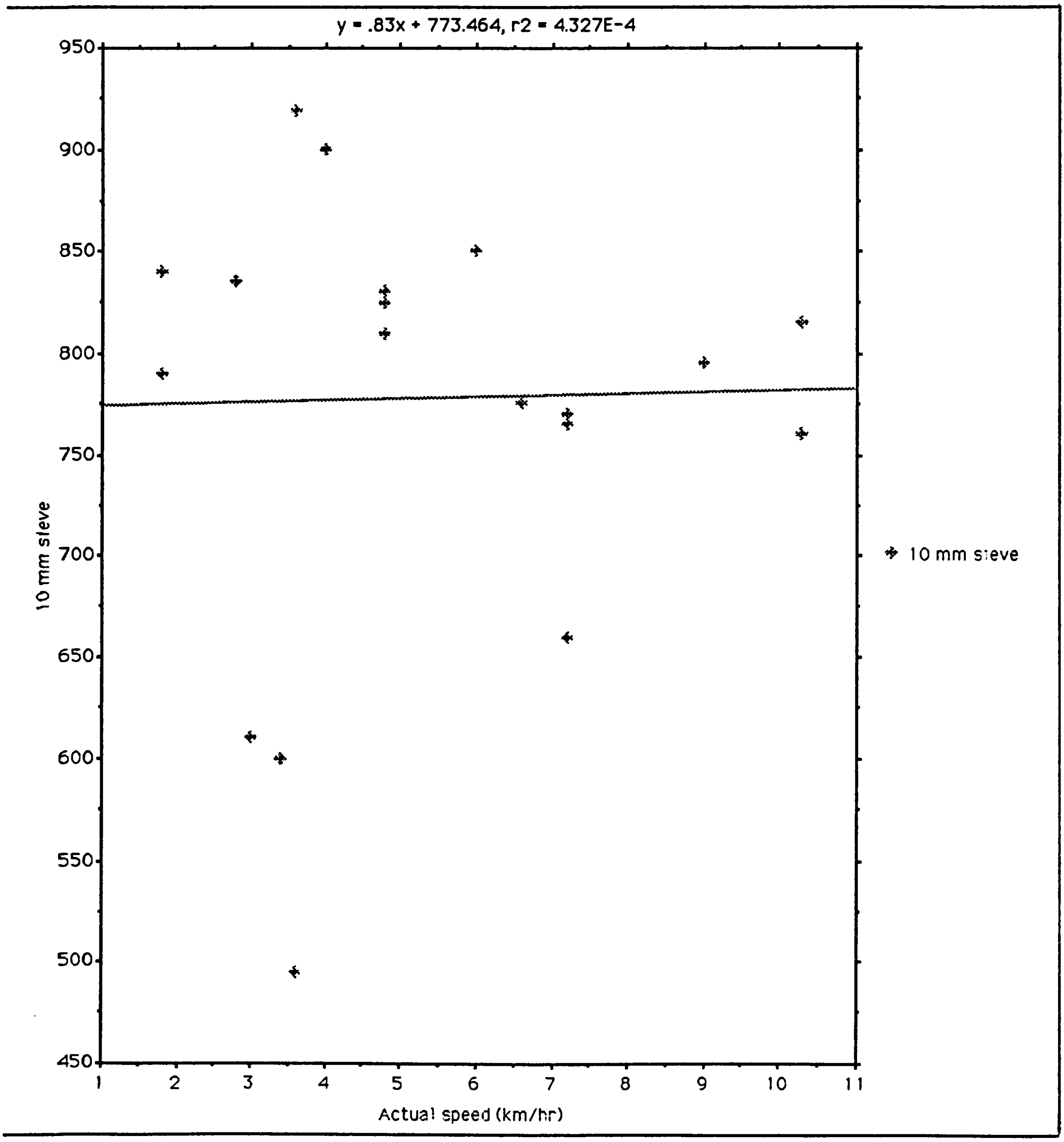

Figure 7 Effect of different forward speeds of the first harrowing on the mean weight of 10mm aggregate size distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

Regressions of mean agregate weight against speed

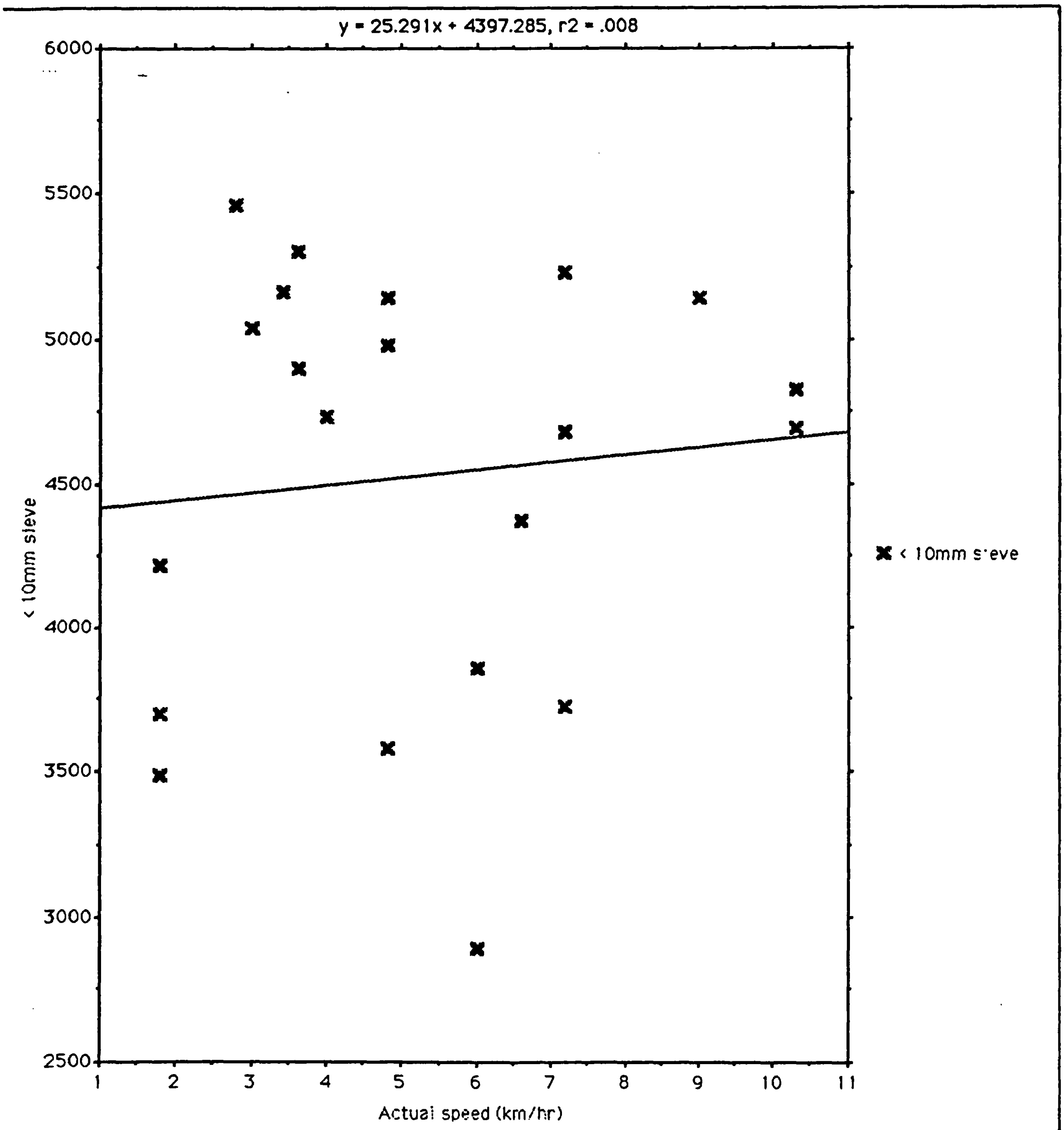

Figure 8 Effect of different forward speeds of the first harrowing on the mean weight of <10mm aggregate size distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

Regressions of mean agregate weight against speed

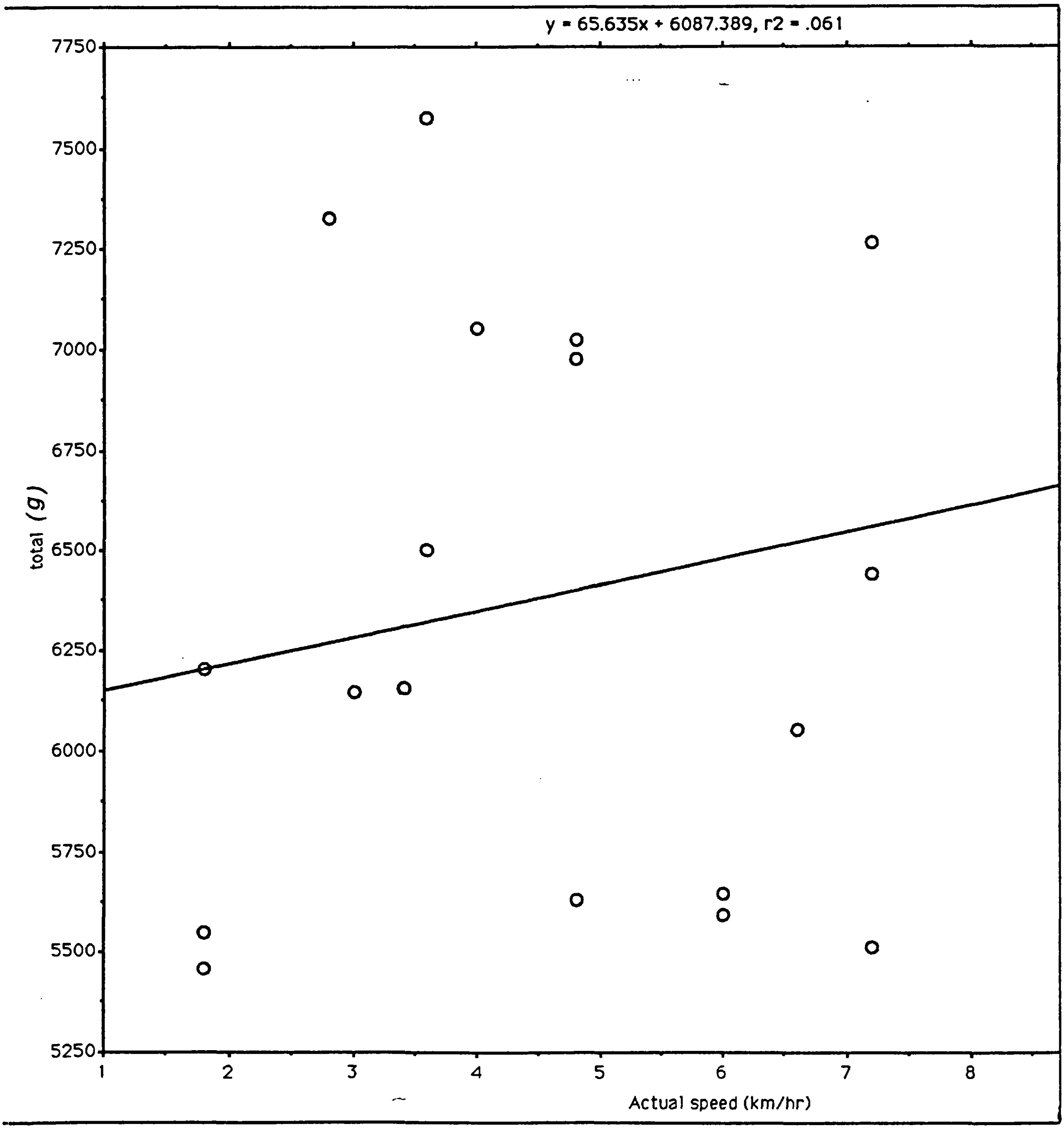

Figure 9 Effect of different forward speeds of the first harrowing on the total mean weight of different aggregate sizes distributed on the soil surface (m.c. = 5.6%) Gezira Station 1993.

Table 4 Effect of penetration resistance (MPa) of the recommended tillage system and different sowing methods at 13 weeks after sowing (M.C.=39.6%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.4900	0.6800	0.9000	1.1000	1.250	1.430	1.6600	2.000
2A	0.5000	0.7200	1.0000	1.1500	1.340	1.450	1.6500	1.980
3A	0.4500	0.6400	0.8700	1.0300	1.220	1.470	1.6700	2.030
4A	0.4100	0.6100	0.8100	1.0300	1.310	1.520	1.7100	2.030
5A	0.4500	0.6300	0.8600	1.0600	1.400	1.600	1.7500	1.990
1B	0.4600	0.6000	0.7400	1.0100	1.250	1.430	1.6500	2.010
2B	0.3900	0.5700	0.7500	1.0000	1.220	1.360	1.6200	2.000
3B	0.3800	0.5400	0.7600	1.0300	1.220	1.360	1.6500	1.960
4B	0.4000	0.5100	0.7500	1.0400	1.220	1.350	1.6100	1.970
5B	0.3800	0.5000	0.7300	0.9800	1.130	1.360	1.6400	1.950
S.e.d.(a)	0.05381	0.04391	0.04087	0.04445	0.1445	0.06326	0.04763	0.0727
S.e.d.(b)	0.05037	0.04613	0.04275	0.04488	0.1451	0.06316	0.04980	0.0709

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 5 Effect of penetration resistance (MPa) of the reduced tillage system and different sowing methods at 13 weeks after sowing (M.C.=39.6%)

	Penetration Depth (cm)							
Sowing Methods	5	10	15	20	25	30	40	50
1A	0.4400	0.6500	0.8300	1.0000	1.160	2.0400	2.4700	2.900
2A	0.4300	0.6300	0.8000	1.0900	1.470	2.0200	2.400	2.850
3A	0.3700	0.6300	0.8100	1.0700	1.490	2.0600	2.3900	2.850
4A	0.4100	0.6100	0.8100	1.0900	1.490	2.0100	2.3600	2.870
5A	0.4000	0.6600	0.8300	1.1000	1.510	2.1000	2.4400	2.830
1B	0.4300	0.7100	0.8800	1.0600	1.430	1.9900	2.3500	2.750
2B	0.4100	0.6800	0.8600	1.0600	1.550	2.0900	2.4200	2.830
3B	0.4200	0.6800	0.9100	1.1100	1.470	2.0700	2.3800	2.830
4B	0.4800	0.7300	0.8700	1.1100	1.500	2.0400	2.3600	2.880
5B	0.4200	0.7000	0.9100	1.0900	1.490	2.0700	2.3700	2.890
S.e.d.(a)	0.05381	0.04391	0.04087	0.04445	0.1445	0.06326	0.04763	0.0727
S.e.d.(b)	0.05037	0.04613	0.04275	0.04488	0.1451	0.06316	0.04980	0.0709

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 6 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 5 cm depth of penetration at 13 weeks after sowing (M.C.= 39.6%)

	Seed Rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.4600	0.4020
Reduced	0.4100	0.4320

S.e.d.(a) = 0.02944
S.e.d.(b) = 0.02252
Significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 7 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 10 cm depth of penetration at 13 weeks after sowing (M.C.= 39.6%)

	Seed rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.6560	0.5440
Reduced	0.6360	0.7000

S.e.d.(a) = 0.01503
S.e.d.(b) = 0.02063
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 8 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 15 cm depth of penetration at 13 weeks after sowing (M.C.= 39.6%)

	Seed Rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	0.8880	0.7460
Reduced	0.8160	0.8860

S.e.d.(a) = 0.01441
S.e.d.(b) = 0.01912
Significant at P = 0.001
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 9 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 20 cm depth of penetration at 13 weeks after sowing (M.C.= 39.6%)

	Seed Rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	1.0740	1.0120
Reduced	1.0700	1.0860

S.e.d.(a) = 0.01909
S.e.d.(b) = 0.02007
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 10 Effect of penetration resistance (MPa) of different tillage systems and two seed rates at 30 cm depth of penetration at 13 weeks after sowing (M.C.= 39.6%)

	Seed-rate Level	
Tillage System	60 kg/f	40 kg/f
Recommended	1.4940	1.3720
Reduced	2.0460	2.0520

S.e.d.(a) = 0.02848
S.e.d.(b) = 0.02824
Significant at P = 0.01
a: For comparing means with different tillage systems.
b: For comparing means with same tillage system.

Table 11 Effect of recommended tillage system with different sowing methods on wheat establishment at five leaves stage.

Treatment	Plant Density (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	517.0	130.3	24.4	5.57
2A	440.0	175.7	43.4	4.20
3A	653.0	273.0	83.4	3.47
4A	417.0	178.9	45.4	4.30
5A	480.0	182.8	40.1	4.50
1B	370.0	95.3	29.3	3.63
2B	257.0	151.7	28.7	5.03
3B	377.0	209.5	67.4	3.60
4B	340.0	174.6	40.1	4.97
5B	247.0	152.8	52.4	4.07
S.e.d.(a)	148.0	56.75	19.17	1.333
S.e.d.(b)	150.4	53.83	17.79	1.147

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 12 Effect of reduced tillage system with different sowing methods on wheat establishment at five leaves stage.

Treatment	Plant Density (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	660.0	165.4	34.1	5.17
2A	550.0	208.4	41.8	5.33
3A	497.0	177.2	46.9	3.83
4A	520.0	229.0	43.1	6.10
5A	423.0	187.4	40.2	4.73
1B	520.0	195.3	43.0	5.30
2B	190.0	135.3	35.4	4.07
3B	647.0	254.4	54.7	5.23
4B	487.0	204.5	49.2	4.13
5B	450.0	231.4	52.9	4.73
S.e.d.(a)	148.0	56.75	19.17	1.333
S.e.d.(b)	150.4	53.83	17.79	1.147

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 13 Effect of recommended tillage system with different sowing methods on wheat establishment at flowering stage.

Treatment	Plant Density (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	380.0	710.0	58.1	12.93
2A	597.0	664.0	49.7	14.87
3A	427.0	647.0	47.3	18.57
4A	387.0	506.0	35.1	14.43
5A	410.0	495.0	47.5	10.50
1B	343.0	522.0	30.8	16.33
2B	323.0	512.0	40.8	12.97
3B	493.0	531.0	65.1	11.47
4B	470.0	569.0	49.2	12.23
5B	527.0	545.0	37.7	14.47
S.e.d.(a)	140.0	126.3	13.88	3.891
S.e.d.(b)	139.2	126.4	14.60	3.956

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 14 Effect of reduced tillage system with different sowing methods on wheat establishment at flowering stage.

Treatment	Plant Density (Plants/m^2)	Shoot Dry Weight (g/m^2)	Root Dry Weight (g/m^2)	Shoot:Root Ratio
1A	540.0	465.0	28.4	17.33
2A	520.0	606.0	34.8	18.03
3A	523.0	673.0	66.8	11.67
4A	613.0	681.0	42.2	17.30
5A	443.0	442.0	22.2	21.00
1B	627.0	735.0	39.2	18.67
2B	407.0	643.0	57.4	11.07
3B	453.0	444.0	36.3	17.30
4B	347.0	505.0	46.5	11.17
5B	430.0	569.0	46.0	12.60
S.e.d.(a)	140.0	126.3	13.88	3.891
S.e.d.(b)	139.2	126.4	14.60	3.956

a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 15 Effect of different depths of disc harrowing on plant density and yield components

Depth of Harrowing	Plant Height (cm)	No. of Plants m^2	No. of Heads m^2	No. of Seeds per head	Wt 1000 Seeds (g)	Biological Yield (kg/ha)	Harvest Index H.I. %	Grain Yield (kg/ha)
5 cm	71.08	411.0	409.0	4.93	33.63	2407.0	9.10	610.0
10 cm	68.83	382.0	381.0	5.93	34.63	2528.0	11.30	811.0
15 cm	69.75	343.0	340.0	5.70	35.88	2391.0	10.55	701.0
20 cm	69.25	325.0	324.0	5.85	34.25	2226.0	11.20	701.0
25 cm	69.00	343.0	342.0	5.55	35.13	2412.0	10.27	700.0
S.e.d.	2.269	47.0	46.2	0.697	1.552	242.0	1.021	112.9

Not significant at P = 0.05

Table 16 Effect of recommended tillage system with different sowing methods on plant density and yield components

Treatments	Plant Height (cm)	No. of Plants m^2	No. of Heads m^2	No. of Seeds per head	Wt 1000 Seeds (g)	Biological Yield (kg/ha)	Harvest Index H.I. %	Grain Yield (kg/ha)
1A	74.11	540.0	539.0	11.67	34.50	2536.0	30.27	2127.0
2A	73.44	492.0	490.0	11.63	36.50	3192.0	22.23	1982.0
3A	66.11	486.0	484.0	10.37	35.67	2562.0	23.10	1580.0
4A	68.78	428.0	426.0	11.87	35.33	2620.0	22.83	1594.0
5A	72.56	497.0	497.0	12.47	35.33	3344.0	22.60	2071.0
1B	70.55	566.0	566.0	10.03	35.67	2955.0	18.97	1558.0
2B	76.67	440.0	437.0	15.90	35.50	2564.0	28.70	2071.0
3B	67.89	474.0	472.0	11.80	24.83	2940.0	24.27	1940.0
4B	67.67	549.0	544.0	11.00	34.67	2943.0	21.67	1743.0
5B	65.22	408.0	406.0	10.90	34.83	2775.0	26.57	2019.0
S.e.d.(a)	6.271	105.4	105.0	2.115	1.243	521.3	4.140	487.1
S.e.d.(b)	4.321	105.1	104.9	1.692	1.218	509.4	3.296	403.1

Not Significant at $P = 0.05$
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 17 Effect of reduced tillage system with different sowing methods on plant population and yield components

Treatments	Plant Height (cm)	No. of Plants m^2	No. of Heads m^2	No. of Seeds per head	Wt 1000 Seeds (g)	Biological Yield (kg/ha)	Harvest Index H.I. %	Grain Yield (kg/ha)
1A	70.67	494.0	494.0	12.27	33.33	3331.0	25.20	2313.0
2A	74.78	528.0	526.0	10.57	36.67	2959.0	21.77	1784.0
3A	74.45	487.0	484.0	12.27	36.17	3249.0	24.37	2160.0
4A	73.45	543.0	541.0	12.87	35.83	2505.0	26.60	1857.0
5A	74.67	451.0	449.0	16.87	35.17	3176.0	28.13	2569.0
1B	73.11	466.0	462.0	10.87	34.0	3128.0	22.83	1955.0
2B	68.22	359.0	356.0	14.57	35.00	1787.0	27.20	1347.0
3B	72.33	407.0	398.0	15.07	35.83	2347.0	29.97	1952.0
4B	70.22	509.0	508.0	11.03	34.67	2930.0	23.87	1862.0
5B	71.11	341.0	337.0	15.40	37.17	2415.0	28.87	1944.0
S.e.d.(a)	6.271	105.4	105.0	2.115	1.243	521.3	4.140	487.1
S.e.d.(b)	4.321	105.1	104.9	1.692	1.218	509.4	3.296	403.1

Not significant at $P = 0.05$
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 18 Effect of different tillage systems with sowing methods on the number of grains per head as one of the yield components

	Tillage System	
Sowing Methods	Plant Height (cm)	No. of Plants m^2
1	10.85	11.57
2	13.77	12.57
3	11.08	13.67
4	11.43	11.95
5	11.68	16.13

S.e.d.(a) = 1.745
S.e.d.(b) = 1.196
Not significant at P = 0.05
a: For comparing means with different tillage systems.
b: For comparing means with the same tillage system.

Table 19 Effect of different sowing methods with two seed rate levels on the number of grains per head

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	11.97	10.45
2	11.10	15.23
3	11.32	13.43
4	12.37	11.02
5	14.67	13.15

S.e.d. = 1.196
Significant at P = 0.01

Table 20 Effect of different sowing methods with two seed rate levels applied on the harvest index

	Seed rate Level	
Sowing Methods	60 kg/f	40 kg/f
1	27.73	20.90
2	22.00	27.95
3	23.73	27.12
4	24.72	22.77
5	25.37	27.72

S.e.d. = 2.331
Significant at P = 0.01

Table 21 Effect of different forward speeds of the first harrowing on the different aggregate sizes distributed on the soil surface. (m.c. = 5.6%) Gezira Station, 1993.

	Actual speed (km/hr)	50 mm sieve	40 mm sieve	30 mm sieve	20 mm sieve	10 mm sieve	< 10mm sieve	total (g)
1	1.8	190	150	170	500	840	3700	5550
2	1.8	220	185	260	480	840	4220	6205
3	1.8	430	170	200	380	790	3490	5460
4	6.0	370	150	85	330	850	3860	5645
5	7.2	360	120	160	370	770	3730	5510
6	6.0	900	220	320	410	850	2890	5590
7	2.8	350	135	140	405	835	5465	7330
8	3.0	115	65	95	225	610	5035	6145
9	3.4	65	40	90	195	600	5165	6155
10	9.0	190	230	235	350	795	5140	6940
11	10.3	660	175	195	360	760	4690	6840
12	10.3	550	145	345	490	815	4825	7170
13	3.6	265	70	170	200	495	5300	6500
14	4.0	340	360	230	495	900	4730	7055
15	3.6	670	306	255	525	919	4900	7575
16	4.8	355	170	250	390	830	4980	6975
17	4.8	310	245	165	340	825	5140	7025
18	4.8	440	150	215	430	810	3585	5630
19	7.2	440	245	175	410	765	5230	7265
20	6.6	160	135	175	435	775	4370	6050
21	7.2	430	235	120	315	660	4680	6440

Table 22 Some chemical parameters of the soils on the experimental site (Sidi Allal Tazi Station, 1994).

Parameters	EC		SAR		ESP		pH	% N	% O.C.	% P	% CEC	% $CaCO_3$	% K
Depth (cm)	0-25	25-100	0-25	25-100	0-25	25-100	7.8	0.061	0.410	5.41	44.7	8.6	7.2
	0.81	2.33	5.4	9.3	4.8	10.2							

Table 23 Mechanical analysis of the soils on the experimental site (Sidi Allal Tazi Station, 1994).

	PARTICLE SIZE DISTRIBUTION %			
Texture	Coarse Sand	Fine Sand	Silt	Clay
Clay	5.6	7.3	29.9	57

Table 24. Maximum Mean Temperature (°C)

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
66/67					22,1	18,7	22,5	22,4	24,8	33,1	33,1	32,0
67/68	29,4	27,0	20,3	15,9	17,0	18,0	18,2	21,7	25,6	29,2	28,7	31,9
68/69	31,5	29,8	20,8	17,5	19,1	18,5	20,6	23,2	30,6	29,0	33,0	31,4
69/70	28,7	24,5	20,8	14,7	17,3	17,3		22,3	26,5	25,9	31,3	29,7
70/71	31,9	26,7	23,0	16,4	15,5	15,1	17,8	15,8	20,1	25,1	28,4	28,4
71/72	28,8	29,5	20,5	19,3	15,1	15,7	17,0	19,8	22,0	23,7	27,4	27,6
72/73	25,5	24,2	20,6	17,8	15,7	15,9	18,4	21,6	24,8	25,8	29,1	31,5
73/74	28,3	24,9	23,4	16,2	17,3	16,9	17,8	18,4	23,5	23,0	32,2	31,4
74/75	28,1	23,4	21,8	20,1	10,9	19,0	17,9	20,0	21,8	26,5	34,1	32,0
75/76	21,0	27,4	22,8	19,0	10,9	19,0	19,9	20,0	21,0	26,5		32,0
76/77	27,7	21,9	18,5	18,4	16,2	16,7	21,3	24,1	22,0	23,8	26,4	27,7
77/78	29,7	24,3	21,3	18,0	16,5	18,9	19,5	19,7	21,6	23,8	32,3	31,1
78/79	32,2	26,4	23,9	19,5	18,5	18,5	17,8	21,5	24,5	25,1	27,9	27,8
79/80	27,8	22,5	22,0	17,9	16,0	19,2	20,0	22,0	23,0	29,5	31,9	31,7
80/81	31,8	26,6	20,2	16,7	18,4	18,0	23,1	19,9	22,8	28,3	30,0	29,3
81/82	28,2	27,3	27,1	19,5	17,7	18,3	21,1	21,5	25,2	27,4	28,6	30,5
82/83	28,4	23,5	20,1	16,5	18,5	17,2	21,9	22,9	22,7	28,9	26,6	28,1
83/84	31,7	30,7	22,6	18,6	16,2	17,6	18,7	25,0	20,1	25,8	32,5	29,9
84/85	29,2	26,2	20,2	18,7	16,0	21,0	20,0		24,5	27,8	32,4	30,2
85/86			22,5	18,2		17,0	18,5	18,8	26,9	24,0	30,3	29,4
86/87	23,3										30,5	30,6
87/88	31,2	23,8	21,3	18,9	19,8	18,7	21,5	23,0	23,5	25,9	31,4	31,5
88/89	33,9	26,5	22,4	18,8	18,0	19,0	21,9	20,9	24,0	27,4	33,1	32,2
89/90	31,0	29,2										
90/91	29,2	24,0	20,7	17,2	17,3	16,3	17,7	17,6	25,5	28,0	32,7	32,2
91/92	28,9	23,2	20,9	19,0	17,8	20,2	20,9	22,5	26,0	24,2	30,3	31,3
92/93												
93/94	25,6	22,3	19,0	16,7	16,8	17,8	21,6	21,9	24,2	28,5	31,5	29,5
94/95	27,4	26,1	23,3	19,7	18,0	19,5	22,2	24,0	27,5	26,8	31,7	

Sidi Allal Tazi Meteorological Station

Table 25 Minimum Mean Temperature (°C)

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
67/68	9,3	8,1	3,7	2,6	3,0	3,3	5,0	9,3	10,3	13,7	13,1	11,9
68/69	10.2	9,3	3,4	4,2	4,8	3,5	5,0	3,6	9,7	13,9	18,0	16,7
69/70	17,2	13,7	10,0	5,3	10,0	7,3		9,3	12,2	14,9	15,6	18,3
70/71	17,9	12,8	6,1	5,3	8,1	7,2	7,4	10,4	11,7	14,3	18,4	17,3
71/72	16,4	13,9	8,0	6,1	6,5	7,7	8,7	9,2	10,7	13,9	16,7	17,4
72/73	15,5	14,3	9,3	5,4	0,5	5,1	8,8	8,0	13,4	15,3	17,2	18,7
73/74	15,9	11,4	11,0	6,4	7,3	7,2	7,8	9,5	11,8	15,1	19,2	18,3
74/75	15,9	10,2	7,8	3,4	5,3	7,4	7,1	8,3	10,8	10,9	16,0	17,6
75/76	14,4	13,8	6,0	6,4								
76/77	20,5	10,4	4,5	7,2	1,3	0,9	2,1	5,0	7,1	8,9	19,4	16,9
77/78	17,7	13,3	9,9	11,8	8,5	9,8	7,8	9,2	11,6	14,7	18,3	18,8
78/79	16,4	12,1	8,5	10,1	11,8	8,0	8,6	8,1	11,0	15,9	16,6	18,3
79/80	17,3	14,1	8,0	5,0	5,6	6,9	8,0	10,4	12,3	13,1	13,1	14,1
80/81	12,3	9,8	6,5	4,1	3,2	3,5	5,0	6,1	6,7	12,2	13,3	13,3
81/82	10,5	9,9	8,6	5,7	3,1	4,2	4,1	6,4	12,2	14,8	15,8	17,4
82/83	14,1	10,1	9,6	7,1	4,8	6,4	9,8	6,5	7,1	12,3	15,0	14,6
83/84	12,9	10,1	9,2	7,0	6,8	8,4	3,2	11,5	8,1	10,3	14,7	14,0
84/85	11,8	6,6	8,6	5,4	5,9	8,0	6,0		11,3	16,0	19,0	19,8
85/86	–	–	10,3	7,7	–	4,7	4,1	4,2	6,8	10,8	11,0	12,1
86/87	13,7										16,6	16,6
87/88	18,7	11,8	6,2	5,7	3,8	2,6	3,2	8,5	8,2	14,1	16,8	14,4
88/89	15,6	11,7	10,5	2,4	2,4	3,4	5,3	3,5	7,3	10,8	13,6	15,1
89/90	11,7	11,9										
90/91	14,0	9,8	4,4	3,2	3,2	2,7	3,5	3,7	11,4	16,3	14,5	15,7
91/92	11,4	9,4	3,5	4,7	2,6	14,0	3,5	6,0	8,5	10,0	13,5	12,0
92/93												
93/94	15,5	12,1	10,0	6,7	4,4	5,6	9,1	8,9	12,5	15,1	19,0	19,4
94/95	15,2	15,0	11,7	6,1	5,2	7,5	9,9	11,4	14,8	16,1	18,7	

Sidi Allal Tazi Meteorological Station

Table 26 Rainfall at Sidi Allal Tazi (mm)

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	TOT
67/68	0,0	0,0	150,5	50,5	1,5	138,0	53,0	33,0	15,0	3,0	0,0	2,5	447,0
68/69	1,1	0,2	198,5	129,7	80,7	130,1	92,3	80,5	6,0	8,8	9,5	0,0	737,4
69/70	43,6	41,9	103,4	113,4	188,2	2,0	51,0	53,5	28,8	6,5	0,0	0,0	632,3
70/71	0,0	45,7	32,9	117,0	121,0	27,4	138,3	165,1	99,0	6,5	0,0	0,0	752,9
71/72	0,0	0,0	93,4	109,2	102,7	97,3	126,9	33,9	55,5	0,3	0,0	0,0	619,2
72/73	26,0	70,1	19,1	49,7	67,8	68,7	68,4	2,3	33,3	0,0	0,0	4,0	409,4
73/74	0,7	8,3	15,0	213,9	30,2	74,2	83,9	168,9	7,4	20,8	0,0	0,0	623,3
74/75	0,8	5,4	5,5	0,0	64,8	60,9	122,9	34,8	16,5	0,0	0,0	0,0	311,6
75/76	0,0	0,0	34,2	188,5	51,6	40,5	34,0	67,7	89,8	0,7	0,0	0,0 q	
76/77	2,0	138,3	3,5	177,1	149,4	109,7	9,8	5,5	24,0	3,0	0,0	0,0	622,3
77/78	0,0	41,0	57,1	103,3	140,5	96,5	29,6	82,0	29,0	9,0	0,0	0,0	588,0
78/79	0,0	14,0	14,7	215,5	120,5	168,0	81,0	41,5	0,5	0,0	0,0	0,0	655,7
79/80	0,0	175,0	25,5	27,0	59,0	8,0	72,5	26,5	31,0	0,0	0,0	0,0	424,5
80/81	1,5	50,5	173,5	33,5	18,0	28,9	43,5	96,8	28,5	3,5	0,0	0,0	478,2
81/82	4,0	5,5	0,0	147,1	106,3	61,8	23,0	161,7	1,5	0,0	0,0	0,0	510,9
82/83	5,0	44,9	87,4	59,2	0,0	153,3	45,0	36,3	3,5	0,0	0,0	0,0	434,6
83/84	0,0	0,0	193,3	153,3	42,0	32,5	71,0	26,0	158,6	0,0	0,0	0,0	676,7
84/85	0,0	10,5	190,0	21,7	69,0	22,0	14,6	14,5	16,5	0,0	0,0	0,0	358,8
85/86	13,5	0,0	81,7	77,0	103,0	160,5	44,5	44,5	0,0	7,0	0,0	0,0	531,7
86/87	2,0	11,5	70,0	28,0	148,5	131,0	4,0	18,0	0,0	0,0	2,0	25,0	440,0
87/88	9,0	64,0	151,5	136,5	125,0	28,0	12,0	30,0	8,0	0,0	0,0	0,0	564,0
88/89	0,0	18,0	151,0	30,0	57,0	118,0	105,0	125,0	0,0	0,0	0,0	0,0	604,0
89/90	0,0	27,0	178,0	196,0	105,0	10,0	55,0	55,0	8,0	0,0	0,0	0,0	634,0
90/91	1,7	56,4	68,0	190,0	14,0	141,0	183,0	6,0	0,3	6,4	0,0	0,0	666,8
91/92	91,9	56,4	6,5	30,0	5,0	49,5	30,0	71,0	19,0	17,5	0,0	0,0	376,8
92/93	0,0	78,5	22,0	30,0	10,0	6,0	55,5	84,6	47,8	0,0	0,0	0,0	334,4
93/94	4,0	92,5	193,5	16,0	66,0	82,5	16,0	23,0	38,0	0,0	0,0	0,0	531,5
94/95	4,5	48,0	83,0	2,5	10,5	41,0	19,8	23,7	0,0	0,0	0,0	0,0	233,0

Sidi Allal Tazi Meteorological Station

Table 27 Number of Rainfall Days at Sidi Allal Tazi

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	TOT
67/68	0	5	11	8	1	17	12	7	2	2	0	2	67
68/69	1	1	15	10	0	10	0	0	0	0	0	0	37
69/70	5	7	19	12	18	1	0	4	5	4	0	0	75
70/71	0	18	5	12	12	5	12	15	15	0	0	0	94
71/72	1	0	14	15	15	18	18	2	8	1	0	0	92
72/73	5	11	8	10	8	11	10	2	4	0	0	3	72
73/74	1	2	8	12	6	12	9	17	2	9	0	0	78
74/75	1	4	4	0	9	6	15	7	4	1	0	0	51
75/76	0	0	5	11	3	8	8	10	5	2	0	0	52
76/77	1	13	4	15	17	10	3	1	3	1	0	0	68
77/78	0	8	6	11	12	8	6	8	6	0	0	0	65
78/79	0	5	14	14	10	7	4	1	1	0	0	0	56
79/80	0	10	5	4	5	4	10	5	7	0	0	0	50
80/81	2	15	9	6	3	9	5	13	5	2	0	0	69
81/82	2	3	1	15	10	8	2	13	1	0	0	0	55
82/83	2	6	10	7	0	15	5	8	1	0	0	0	54
83/84	0	1	13	9	7	6	9	4	13	0	0	0	62
84/85	0	3	16	3	13	6	5	5	5	0	0	0	56
85/86	3	0	10	8	12	15	8	10	0	1	0	0	67
86/87	1	2	5	5	11	11	2	3	0	0	1	2	43
87/88	1	6	13	13	14	6	2	3	3	0	0	0	61
88/89	0	5	10	25	5	10	5	8	0	0	0	0	68
89/90	0	1	12	12	6	1	4	6	2	0	0	0	44
90/91	0	2	7	7	14	3	12	11	2	1	4	0	63
91/92													
92/93													
93/94	1,0	10,0	14,0	1,0	5,0	8,0	1,0	3,0	3,0	0,0	0,0	0,0	46,0
94/95	2,0	5,0	2,0	1,0	3,0	3,0	4,0	5,0	0,0	0,0	0,0	0,0	25,0

Sidi Allal Tazi Meteorological Station